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Government of Ireland

Energy Efficiency in Traditional Buildings

Draft guidance for public consultation

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GLOSSARY OF TERMS

Building Renovation Passport: A master plan for the deep energy retrofit of a building which sets out the upgrade measures step by step.

Carbon Dioxide Equivalent: The carbon dioxide equivalent (CO_2eq) is used as a standard unit to measure the environmental impact of one tonne of different greenhouse gases compared to the impact of one tonne of CO_2.

Embodied Emissions: Carbon emissions result from the production, transportation and installation of building materials and components on site. Embodied emissions also include emissions from maintenance, repairs, replacement and ultimately the demolition and disposal of building materials over the full lifetime of the building.

Environmental Product Declaration: Standardised documents used to communicate the environmental performance of a product.

Global Warming Potential: a measure of how much heat a greenhouse gas traps in the atmosphere, relative to carbon dioxide. Carbon dioxide has a GWP of 1, methane has a GWP of 25 and nitrous oxide has a GWP of 265.

Heat Loss Indicator: A measure of the rate of heat loss from a building through the building fabric and ventilation, based on the building's floor area (W/Km^2).

Heat Pump: An electrical device that is utilised to transfer heat energy from a heat source (air, ground or water) to a heat sink (internal space of a building).

Hygroscopic: A hygroscopic material has the ability to absorb, transport and release moisture depending on the environmental conditions.

Life Cycle Assessment: LCA is a systematic set of procedures for compiling and examining the environmental impacts directly attributable to a building, infrastructure, product or material throughout its lifecycle (ISO 14040: 2006).

Operational Emissions: Carbon emissions that result from the day-to-day use of a building through energy consumption.

Solar PV: Photovoltaic panels that generate electricity when exposed to light.

Solar Thermal: The name given to a kind of solar panels that produce hot water.

Traditional Building: Buildings of vapour permeable construction, typically built with solid masonry walls, single-glazed windows, and timber-framed roofs.

LIST OF ACRONYMS

ACA	Architectural Conservation Area
ASHP	Air Source Heat Pump
AWHP	Air to Water Heat Pump
BER	Building Energy Rating
BRP	Building Renovation Passport
CFI	Compact Fluorescent Lamps
CHP	Combined Heat & Power
COP	Coefficient of Performance
CO_2eq	Carbon Dioxide Equivalent
DCV	Demand Control Ventilation
DEAP	Dwelling Energy Assessment Procedure
DECC	Department of Environment, Climate and Communications
DHLGH	Department of Housing, Local Government and Heritage
DHW	Domestic Hot Water
EAHPs	Exhaust Air Heat Pumps
EPA	Environmental Protection Agency
EPBD	Energy Performance Building Directive
EPD	Environmental Product Declaration
EWI	External Wall Insulation
GCV	Gross Calorific Value
GSHPs	Ground Source Heat Pumps
GWP	Global Warming Potential
HLI	Heat Loss Indicator
HVAC	Heating, Ventilation and Air Conditioning
IAQ	Indoor Air Quality
IPCC	Intergovernmental Panel on Climate Change

IWI	Internal Wall Insulation
LED	Light Emitting Diode
MHRV	Mechanical Heat Recovery Ventilation
MIC	Maximum Import Capacity
NCV	Net Calorific Value
NEAP	Non-Dwelling Energy Assessment Procedure
O&M	Operation and Maintenance
PIR	Polyisocyanurate
PF	Power Factor
PoE	Power over Ethernet
PV	Photovoltaic
RMP	Record of Monuments and Places
SEAI	Sustainable Energy Authority of Ireland
TGD	Technical Guidance Document
VCL	Vapour Control Layer
WSHPs	Water Source Heat Pumps

General Disclaimer

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1 INTRODUCTION

In May 2019, the Irish government became the second country in the world to declare a climate and biodiversity emergency. The global climate has already warmed by between 0.8°C and 1.2°C since 1900 and efforts must be made to reduce greenhouse-gas emissions and avoid exceeding an increase of 1.5°C[1]. By the mid-century (2041-2060), Ireland's temperatures are expected to increase by 1 – 1.6 ° C (compared to reference period 1981-2000), with increased heatwaves and rainfall events. This means that our buildings will have to be able to deal with higher temperatures, humidity, saturation of building fabric and extreme winds in order to maintain the desired level of thermal comfort and a healthy indoor air quality[2].

It is Government policy to reduce energy use and carbon dioxide emissions from the burning of fossil fuels. The Climate Action and Low Carbon Development (Amendment) Bill 2021 sets out a roadmap for transitioning to a 'climate resilient, biodiversity rich and climate neutral economy by no later than 2050'.

The Energy Performance of Buildings Directive (2002/91/EC) as adopted into Irish law specifically targeted energy requirements of buildings whether new or existing, residential or non-residential. In order to meet the requirements of the directive (as recast and amended), and to address the fact that buildings contribute significantly to this country's energy consumption, the standard of energy conservation required of new buildings has risen significantly in recent years. However, upgrading the thermal performance and energy efficiency of the existing building stock presents numerous challenges, particularly where the building was built using traditional materials and construction methods and is of architectural and/or historical interest. In such cases, additional considerations are warranted.

Under Ireland's Climate Action Plan 2019, 500,000 homes must be retrofitted to a B2 equivalent Building Energy Rating (BER) or cost optimal equivalent or carbon equivalent by 2030. All public sector buildings, of which around 15%[3] are traditional buildings, are to achieve a BER of B by 2030, with around one third of commercial properties aiming to achieve the same target[4]. The EU's Renovation Wave aims to at least double the annual energy renovation rates in the next ten years. While the current emphasis on energy retrofit of existing buildings is important, the integrity of these buildings, some of which will be traditional buildings which have a cultural heritage value, needs to be respected. The specific physical properties and existing thermal performance of traditional buildings must be considered as part of the retrofit strategy to bring these buildings as near to a BER rating of B2 for dwellings or B for a public/commercial buildings as possible. The risks of applying energy efficiency methods designed for use on modern construction to traditionally built buildings include damage both to the building fabric and to the health of the building occupants.

The Sustainable Energy Authority of Ireland (SEAI) estimates that around 60% of homes in the country have a BER rating of C3 or worse. Many of the buildings that fall within the lowest BER brackets are of traditional construction, even though research has found that in some cases traditional solid masonry walls can outperform

[1] Intergovernmental Panel on Climate Change (2018) Global Warming of 1.5°C: https://www.ipcc.ch/sr15/
[2] Regional climate models for Ireland can be found the EPA Research Report No. 159: http://www.epa.ie/pubs/reports/research/climate/research159ensembleofregionalclimatemodelprojectionsforireland.html
[3] Seamus Hoyne (2021) Discussion regarding data from Public Sector Retrofit analysis for the Department of Public Expenditure and Reform and Department of the Environment Climate and Communications
[4] Department of Environment Climate and Communications (2020) Ireland's Long Term Renovation Strategy. Dublin: Department of Environment, Climate and Communications. Available at: https://www.gov.ie/en/publication/a4d69-long-term-renovation-strategy/

the default U-values assigned to them[5]. SEAI proposes to fund research to update the default U-values for solid masonry walls found in traditional buildings in Ireland.

People enjoy old buildings for the sense of history they evoke, the craftsmanship they represent and for the solidity of their construction. However, there is often a perception that old buildings are cold and draughty. While this can be true, the degree to which their users are willing to tolerate any shortcomings in comfort is testimony to the value people place on architectural character and a sense of place. Historically, heating solutions included a roaring fire or an ever-burning stove emitting pleasurable warmth. Previously, people may have had different expectations in terms of heat and comfort. Extra clothing and bedclothes, hot water bottles and even different dietary habits played their part in keeping people warm in their day-to-day lives during the colder months. From the mid twentieth century onwards, the availability of cheap fossil fuels enabled an increasing number of households to avail of central heating, supplying heat to all rooms; a concept almost unheard of in earlier times.

Now, however, there is an increasing awareness of the importance of energy and fuel conservation. In tandem with higher expectations in relation to the general warmth and comfort of the indoor environment, this awareness has led to new standards and types of building construction intended to ensure that the energy consumed by a building during its useful life is minimised. These new standards in modern buildings have influenced the expectations of users of older buildings. Building professionals must also consider the architectural character, repair and maintenance history, properties of the traditional construction materials and older forms of construction for each individual building.

This document is an updated and expanded edition of the Advice Series publication (2010) "Energy Efficiency in Traditional Buildings"[4] and is primarily aimed at building professionals, specialist crafts people and installers working in the retrofit (building energy upgrade) sector. This document provides strategic rather than prescriptive guidance on how to improve the energy efficiency of traditional residential and non-residential buildings and how to avoid unintended consequences in the process. The aim of retrofit works should be to improve the energy efficiency as far as is reasonably practicable. The work should not unnecessarily:

(a) prejudice the architectural and historic character of the building,

(b) increase the risk of long-term deterioration of the building fabric or fittings, nor

(c) jeopardise the health and well-being of the occupants.[6]

1.1 WHAT IS A 'TRADITIONAL BUILDING'?

There are a wide variety of traditional buildings that differ from one locale to another but in Ireland they generally include those built with solid masonry walls of brick and/or stone or sometimes compacted mud, often with a lime render finish, single-glazed timber or metal framed windows and a timber-framed roof usually clad with slate but often with tiles, copper or lead or less commonly with corrugated iron or thatch. This was the

[5] Baker, P. (2011) Technical Paper 10: U‐values and Traditional Buildings - In Situ Measurements and their Comparisons to Calculated Values, Edinburgh: Historic Environment Scotland. Available at: https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=16d0f7f7-44c4-4670-a96b-a59400bcdc91

[6] Technical Guidance Document L- Conservation of Fuel and Energy – Dwellings (2019), Department of Housing, Local Government and Heritage. https://www.gov.ie/en/publication/d82ea-technical-guidance-document-l-conservation-of-fuel-and-energy-dwellings/#current-edition

dominant form of building construction in Ireland from medieval times until the second quarter of the twentieth century.

Traditional solid masonry walls come in many varieties (see Figure 1), but the key unifying factor is that they do not contain a cavity (see Figure 2 and Figure 3). Traditional materials and construction techniques allow for the natural transfer of heat and moisture. Solid masonry walls therefore relied on their thickness to cope with atmospheric moisture, being sufficiently thick to ensure that drying out took place before moisture from rainwater passed through the wall to cause damp on the inner face. Many traditional buildings in Ireland were built in this manner and **it is therefore essential that all materials and finishes, including mortars, renders and plasters, used on traditional walls are porous to allow this natural movement of moisture to continue.** A selection of typical traditional wall build-ups is shown in Figure 1 below but it should be noted that this is not a definitive list and variations in materials, construction and thicknesses are to be expected.

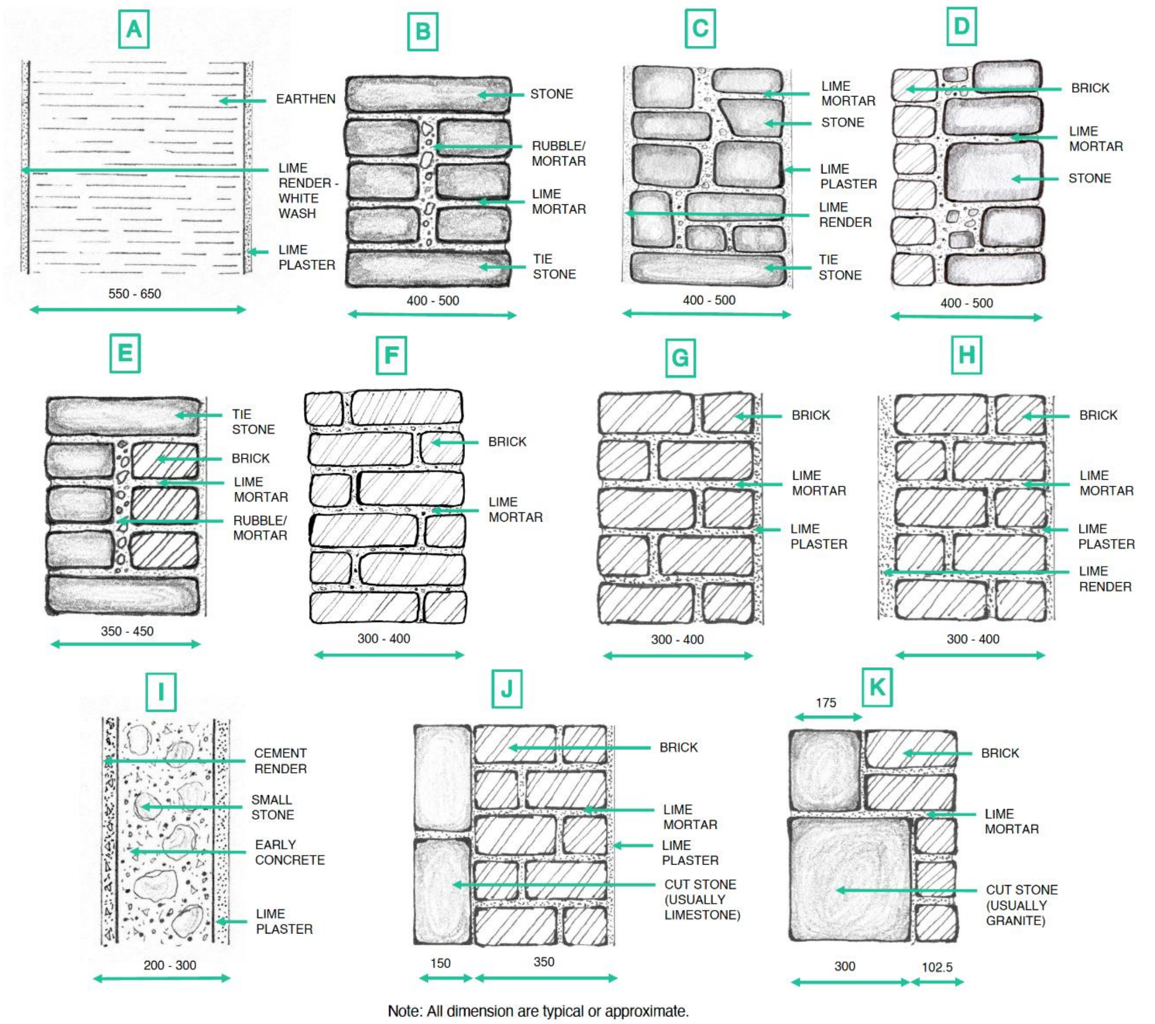

Figure 1 Different types of traditional masonry walls and their typical build up.

Modern construction is largely distinguished by the development and widespread use of twin-leafed construction, commonly called a cavity wall, which is based on a fundamentally different approach to keeping the interior of a building dry than that of a traditional solid masonry wall. The cavity wall consists of an outer leaf which is presumed always to be wet, and an inner leaf which it is intended should always be dry, with the air-filled cavity acting as a water barrier. In the earliest cavity wall constructions, the cavity was left empty but latterly was often partially or totally filled with an insulating material. Note: the drawings in Figure 2and Figure 3 are illustrative and not drawn to scale.

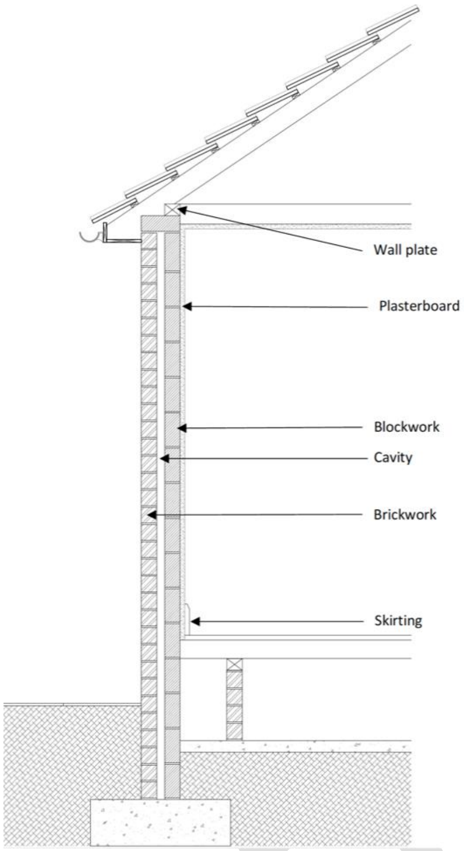

Figure 2 A typical modern cavity wall.

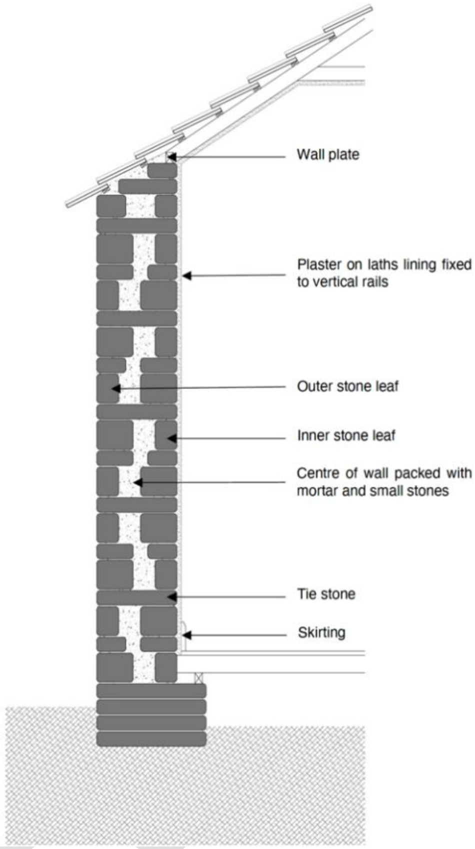

Figure 3 A typical solid masonry wall.

According to the 2016 census records, 9% of all private homes (houses and apartments) in Ireland were constructed prior to 1919 and 7% were constructed between 1919-1945[3]. However, not all buildings built before 1945 are traditional masonry buildings, in fact some early examples of modern construction can be found. For instance, many local authority dwellings built after 1922 were constructed with solid mass concrete walls[7]. However, as this document only provides guidance on the retrofit of traditional vapour permeable construction, guidance on the upgrade of modern construction including early solid concrete walls and early twin-leafed or cavity wall construction should be sought from S.R. 54:2014 Code of practice for the energy efficient retrofit of dwellings[8].

Stylistically, traditional buildings in Ireland can vary to a great extent, from the utilitarian nature of vernacular thatches cottages, industrial warehouses and military barracks to the more refined nature of the Victorian, Georgian and Edwardian dwellings. A small representative selection of traditional buildings can be seen below.

[7] Rowley, E. (2016) More Than Concrete Blocks. Dublin City's Twentieth Century Buildings and Their Stories. 1900-1939. Vol. I. Four Courts Press.
[8] National Standards Authority of Ireland 2019. S.R. 54:2014&A1:2019 Code of practice for the energy efficient retrofit of dwellings. National Standards Authority of Ireland.

Table 1 Example of traditionally built buildings in Ireland.

Flax Thatch building c.1800

Richmond Barracks, 1810

Early Victorian Detached House

Artisan Cottages c.1900

Georgian Mid Terrace over Retail

Victorian Public House

Edwardian Terrace

Georgian End of Terrace

Early 19th Century building with exposed limestone rubble wall

Early Industrial Mill Building

1.2 THE BUILDING ENERGY RATING (BER) AND TRADITIONAL BUILDINGS

The Energy Performance of Buildings Directive promotes energy efficiency in all buildings. One of its requirements is that all new and certain existing buildings within the EU have an energy performance certificate. The implementation of performance certificates in Ireland is managed by SEAI and takes the form of Building Energy Ratings (BER) for all building types, calculated by the Domestic Energy Assessment Procedure (DEAP) for dwellings and by the Non-domestic Energy Assessment Procedure (NEAP) for other building types. Public buildings greater than 250m^2 and large buildings (greater than 500m^2) that are frequently visited by the public are also required to have Display Energy Certificates. The DEAP and NEAP methodologies and software calculate primary energy use, the associated CO_2 emissions and the renewable energy provided for space heating and (where applicable) cooling, ventilation, water heating and lighting under standardised conditions of use. They are also the compliance tool specified in Part L of the Irish Building Regulations. The software and manual are freely available online[9].

BER certificates are now required for all new buildings and, in the case of existing buildings, for premises undergoing transaction, whether lease or sale. While buildings protected under the National Monuments Acts, protected structures and proposed protected structures are exempt from the requirements to have a BER, all other traditionally built buildings are required to have a BER certificate when let or sold. There is currently no requirement that an existing building not undergoing works achieve a particular rating. The BER assesses the energy performance of the building, allowing potential buyers and tenants to take energy performance into consideration in their decision to purchase or rent a property.

Following assessment of the building by a trained assessor, a certificate is prepared and issued to the building owner along with the BER advisory report. The energy rating displays both the energy requirement of the building in terms of 'primary energy' and the resultant carbon dioxide emissions. Normally a building owner thinks in terms of 'delivered energy', also known as 'final energy'. Delivered energy corresponds to the energy consumption that would normally appear on the energy bills of the building. Primary energy includes delivered energy, plus an allowance for the energy 'overhead' incurred in extracting, processing or generating, and transporting a fuel or other energy carrier to the building.

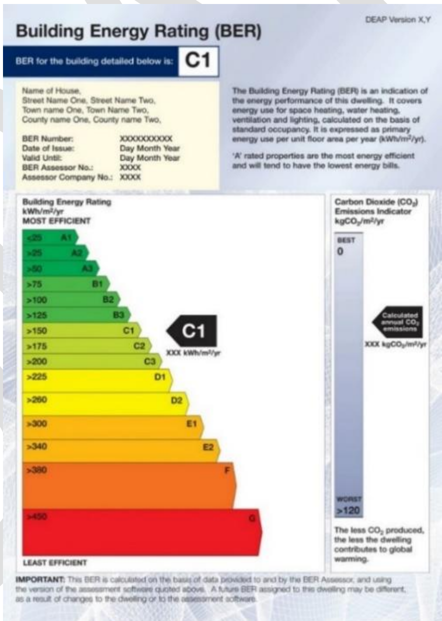

Figure 4 Sample Building Energy Rating Certificate for dwellings. The most energy efficient rating is 'A1' (green) down to the least efficient is 'G' (red)

The objective of BER is to provide an energy rating for buildings, expressed in a familiar form similar to that used for energy-rated domestic appliances such as fridges, based on a standard system of appraisal which allows all properties to be compared regardless of how they are used or occupied. In the assessment methodology, the

[9] DEAP software: https://www.seai.ie/home-energy/building-energy-rating-ber/support-for-ber-assessors/domestic-ber-resources/deap4-software/
NEAP software: https://www.seai.ie/grants/supports-for-contractors/neap/sbemie-software/

size and shape of a building are taken into account and its floor area determines the number of occupants that are assumed. In the case of a dwelling, the rating is based on a standardised heating schedule of a typical household, assuming two hours heating in the morning and six in the evening. A building's BER does not take into account its location within the country (whether in the colder north or warmer south) but does consider orientation relative to the sun. It is also important to bear in mind that it does not take into account the actual energy usage but assumes a standardised usage pattern.

At present, the standard calculation for older buildings relies on default values for heat loss calculations. These defaults are conservative and, at times, may poorly represent an older building's ability to retain heat. For example, there is only one figure for all types of stone, whereas in reality different stone types lose heat at different rates (see Table , Section 3.6). If the BER assessor knows the build-up of the wall they are able to calculate the U-value based on the materials and properties of construction. This, however, can be difficult to determine in traditional buildings without boring a core through the external walls. Embodied energy (see Section 1.5) is currently not accounted for in the BER system; this is an issue that requires more research in order that the characteristics of historic buildings in energy terms may be fully appreciated and recognised.

On completion of a BER calculation for an existing building, the assessment software generates a list of recommendations for upgrading the building in the form of an advisory report. These recommendations have been generally designed for existing buildings of modern construction rather than traditionally built buildings. As the BER assessor is responsible for advising which recommendations are appropriate for a particular property, **it is important to ensure that the assessor understands how traditional buildings perform, as inappropriate recommendations could lead to damage of older building fabric.** A building conservation expert should be consulted prior to undertaking certain recommendations on foot of a BER certificate (see table 3).

1.3 ENERGY RETROFIT OF TRADITIONAL BUILDINGS AND COMPLYING WITH BUILDING REGULATIONS

When considering an energy retrofit one must be cognisant of the statutory obligations such as planning, building regulations and building control.

1.3.1 *PLANNING*

Generally, planning permission is required for any development of land or property unless the development is specifically exempted. Development includes carrying out work (building, demolition, alteration) on, in, over or under land, or buildings and making a material (i.e., significant) change of use of land or buildings. Failure to obtain planning permission where it is required can result in penalties (e.g., significant fines and/or even imprisonment).

Exempted developments are outlined in the Planning and Development Regulations 2001[10] (as amended). Exemptions exist to avoid restrictions on minor developments. The Planning Leaflet from the Office of the Planning Regulator outlines the steps in the planning process, providing answers to common questions[11].

[10] Planning and Development Regulations 2001 Exempted Development: http://www.irishstatutebook.ie/eli/2001/si/600/made/en/print#part2
[11] Planning Leaflets, Office of the Planning Regulator: http://www.opr.ie/planning-leaflets/

1.3.2 *PROTECTED STRUCTURES*

Under the Planning and Development Act 2000, a protected structure (or proposed protected structure) is a structure or part of a structure that a planning authority considers to be of special interest from an architectural, historical, archaeological, artistic, cultural, scientific, social or technical point of view. Details of protected structures are entered by a planning authority in a Record of Protected Structures (RPS), which forms part of the development plan. The RPS is usually recorded in list and map form and is sometimes included as an appendix to the local authority development plan. **The owner and/ or occupier of a protected structure is obliged under the Act to ensure that no damage is caused to the structure whether through active means or neglect.** The definition of a protected or proposed protected structure includes its interior, the land within its curtilage, and any other structures within the curtilage and their interiors. The protection also includes any exterior or interior fixtures and fittings of the structure, or of any structure on land within its curtilage (any land or outbuildings which are/were used for the purposes of the structure).

Planning permission is required for all works that materially affect the character of the structure or any element of the structure that contributes to its special interest. The planning authority advises whether they consider planning permission is necessary in a particular case through the Section 5 [12] and Section 57 [13] declaration processes.

Anyone may seek a Section 5 declaration from a planning authority if they want to establish if a specific development requires planning permission. An owner and/or occupier of a protected structure may seek a Section 57 declaration from a planning authority clarifying the type of works which would or would not materially affect the character of the structure, and which would or would not require planning permission. For example, in the case of structures where the decorative scheme is of special interest, planning permission could be required for interior decorating such as plastering or painting. A Section 57 declaration will indicate the types of works that can be carried out without materially affecting the character of the protected structure or any element of it which contributes to its special architectural, historical, archaeological, artistic, cultural, scientific, social and technical interest, and those which cannot.

Detailed guidance can be found in the statutory guidelines *Architectural Heritage Protection: Guidelines for Planning Authorities*[14] issued under s.28 and s.52 of the Planning and Development Act 2000 (as amended).

1.3.3 *ARCHITECTURAL CONSERVATION AREAS*

An Architectural Conservation Area (ACA) is a place, area, group of structures or townscape that:

- is of special architectural, historical, archaeological, artistic, cultural, scientific, social or technical interest, or
- contributes to the appreciation of a Protected Structure.

The local authority development plan can be consulted to see if a building is within an ACA.

[12] Section 5 Exempted Development
[13] Section 57 of the Planning and Development Act 2000, as amended.
[14] Department of the Arts, Heritage and the Gaeltacht (2011) Architectural Heritage Protection: Guidelines for Planning Authorities. Available at: https://www.dlrcoco.ie/en/heritage/conservation/architectural-heritage-protection-guidelines.

Carrying out works to the exterior of a structure located in an ACA, which would materially affect the character of the area, will require planning permission. Works which may affect the character of an area in an ACA and therefore require planning permission include but are not limited to:

- Removing render from an external wall
- Removing plaster from an internal wall
- Rendering, plastering or painting a previously bare wall
- Changing the type of slate or roofing material
- Changing the height or configuration of a roof
- Changing the type, design or material of windows
- Changing the design or materials of a shopfront
- Changing the design or material of external doors
- Changing the design, dimensions, position or material of a chimney.
- Changing the design or materials of window sills
- Adding, removing or altering architectural details, elements, finishes such as quoins, mouldings, fascias, bargeboards, ridge-tiles, jostle stones, paving or kerbing, chimney caps or pots, plaques, railings, gates etc.

Where there is doubt as to whether or not works will affect the character of an area, advice should be sought from the Architectural Conservation Officer in the local authority.

1.3.4 *BUILDING REGULATIONS*

Building Regulations came into force in Ireland in July 1991. As the Building Regulations are generally written to apply to new construction, the DHLGH publication *Bringing Back Homes*[15] explains how the regulations apply to existing buildings in Appendix 2.

Building regulations provide that when a building undergoes “major renovation”, the minimum energy performance requirement of the building or the renovated part thereof, is upgraded in order to meet the cost optimal level of energy performance in so far as this is technically, functionally and economically feasible. “Major renovation” means the renovation of a building where more than 25 % of the surface of the building envelope undergoes renovation. The surface area of the building thermal envelope means the entire surface area of a building through which it can lose heat to the external environment or the ground, including all heat loss areas of walls, windows, floors and roof.

The Elemental works that are included in the surface area calculation for major renovation are summarised in Table 2. According to Technical Guidance Document (TGD) Part L, where major renovations to walls, roofs and ground floors constitute essential repairs, e.g., repair or renewal of works due to fire, storm or flood or damage as a result of a material defect, it is not considered economically feasible to bring these renovations to a cost optimal level. Additionally, painting, re-plastering, rendering, re-slating, re-tiling and insulation of ceiling are not considered major renovation works.

[15] Department of Housing Local Government and Heritage (2018) Bringing Back Homes - Manual for the Reuse of Existing Buildings. Available at: https://www.gov.ie/en/publication/68a5b-bringing-back-homes-manual-for-the-reuse-of-existing-buildings/.

Table 2 Elemental works that are included in the 25% surface area calculation for major renovation.

External Walls Renovation	External insulation of the heat-loss walls Replacement or upgrade of the external walls' structure Internal lining of the surface of heat-loss walls
Windows Renovation	Replacement of windows
Roof Renovation	Replacement of roof structure
Floors Renovation	Replacement of floors
Extension	Extension works which affect more than 25 % of the surface area of the existing dwelling

For dwellings, the cost optimal level achieved by:

a) Reaching an energy performance target of no more than 125 kWh/m2 /yr when calculated in DEAP, or

b) Implementing the energy performance improvements as set out in column 3, Table 7 of Technical Guidance Document L - Dwellings, as far as they are technically, functionally and economically feasible (see Appendix 6.1.3).

For buildings other than dwellings, upgrading the heating, controls, ventilation and lighting systems to modern standards of energy efficiency is generally considered cost optimal. Alternatively, minimum whole building energy performance targets for different buildings by use have been calculated as cost optimal.

This document specifically provides guidance on complying with the following Building Regulations when improving the energy efficiency of traditional buildings[16]:

- TGD Part C - Site Preparation and Moisture Resistance (2020)
- TGD Part D - Materials & Workmanship (2013)
- TGD Part F - Ventilation (2009)
- TGD Part J - Heat Producing Appliances (2014)
- TGD Part L - Conservation of Fuel & Energy - Dwellings (2017 & 2019)
- TGD Part L – Conservation of Fuel & Energy – other than dwellings (2017)

It is also important to consider the following:

- TGD Part A – Structures (2012)
- TGC Part B – Fire Safety (2006)
- TGD Part K – Stairways, Ladders, Ramps and Guards (2014)
- TGD Part H – Drainage and Waste Water Disposal (2016)

For existing buildings, the applicable requirements of TGD Part L are covered by Section 2, which includes specific provisions that apply to the replacement of external doors, windows and roof lights and to the replacement oil or gas boilers.

[16] Technical Guidance Documents available at: https://www.gov.ie/en/collection/d9729-technical-guidance-documents/

1.3.5 *BUILDING CONTROL*

All construction works must follow the Building Control Acts 1990 – 2014 (primary legislation) and the Building Control Regulations 1997 – 2018 (procedures to support compliance).

Building control is now supported nationally by a shared services delivery model across the local government sector. The National Building Control Office has been established within Dublin City Council and there is national and regional support and coordination in place.

Section 4 of the Building Control Acts 1990 – 2014 allows for certain dispensation or relaxation of building regulations and stipulates the procedure to be followed to request a dispensation or relaxation, where appropriate. Contact must be made with the local building control office in advance of application to discuss any dispensation, to help clarify if a contradiction occurs between different requirements of the regulations.

1.4 THE IMPORTANCE OF HAVING THE RIGHT SKILLS

When retrofitting a traditional building it is important it is done properly. Where not approached properly, by people with the right skills, or in line with this guidance, it is likely to result in poorer energy performance and may lead to adverse consequences for or damage to the building fabric and the wellbeing of its occupants.

Any advisor should be independent and objective. They should understand traditional buildings, have experience in dealing with them (including with the type of building in question) and have the relevant professional training to work with them.

The interpretation and application of the more technical recommendations in this guide should be entrusted to suitably qualified persons. When employing a professional advisor or a building contractor, check their qualifications and status with the relevant bodies and institutes first[17]. Ask for references and for the locations and photographs of recent similar work undertaken. Do not be afraid to follow up the references and to visit other building projects. A good advisor should be able to undertake an inspection of a property, recommend options for upgrading its energy efficiency, specify the work required, get a firm price from a suitable builder and oversee the work on site as it progresses.

A building professional with conservation expertise will have experience working on traditional buildings and will be able to advise on suitable measures for traditional building energy upgrades. In Section 3.1.1, Figure 26 general guidelines are provided for determining when a conservation professional is required, who can then further advise on what other professionals may be needed, based on an initial assessment.

The guidance in table 3 will assist in establishing the relevant skills for those involved in a project. It is a list of building professionals that may be needed on a building project, but the team required will differ on a case-by-case basis.

*Note: Further guidance on when and which type of building specialist will be required for certain retrofit measures to be provided in Table 6 - **Error! Reference source not found.** final draft of the guidance document.*

[17] See IGBC/ LIT (2020), Developing a register of building professionals & construction workers who have upskilled in energy renovation – Appendix 9.c for a list of relevant training courses.

Table 3 Essential and recommended qualifications for building professionals.

Building Works Specifier	Role	Essential Qualification	Recommended Qualification
Architect	Design of energy upgrading measures; conservation of the building	Registered architect	Conservation accreditation[18]
Structural Engineer	All structural elements of a building	Registered structural engineer	Conservation accreditation
Building Surveyor	Construction design and building works, project management and monitoring, ensuring compliance with building regulations	Registered building surveyor	Conservation accreditation
Conservation Consultant	Consideration of the effect of any intervention on the existing building fabric, recommendations on conserving and/or improving existing fabric including any traditional features	Conservation Architect Archaeologist Conservation Scientist	Competence in conservation of traditional buildings
Mechanical / Electrical / Energy Engineer	M&E design and specification.	Registered Engineer	Competence in working on traditional buildings
Energy Auditor / BER Assessor	Conducting or validating an Energy Audit /BER assessment to SEAI standards	Domestic Assessors require a NFQ Level 6 Advanced Certificate/Higher Certificate in construction studies. Non – Domestic Assessors require qualification in a building construction-related discipline and membership of professional bodies at the specified grade [19]	On the register of the SEAI, experience with traditional buildings
Thermal Bridge Modeller	Assess compliance for surface temperature (fRsi) and calculation of thermal bridging factors for use in NEAP/DEAP	On the NSAI register of Thermal Modellers[20]	Experience of working on traditionally built buildings
Hygrothermal Modeller	Conduct hygrothermal risk assessment	No register currently available	Relevant experience and/or training + appropriate P.I. cover
Ventilation Validator[21]	Test and validate the quality of the ventilation installation	On the NSAI register of Ventilation Validators[22]	Experience of working on traditionally built buildings

[18] See https://www.riai.ie/work-with-an-architect/conservation-skills
[19] Qualifications necessary for BER Assessors, SEAI: https://www.seai.ie/register-with-seai/ber-assessor/
[20] See: https://www.nsai.ie/certification/agrement-certification/ventilation-validation-registration-scheme/
[21] Mandatory for new built and major renovation as per TGD Part L of the building regulations. Optional for all other renovations.
[22] See: https://www.nsai.ie/certification/agrement-certification/ventilation-validation-registration-scheme/

Air Permeability Tester	Test and certify the airtightness level to be inserted into NEAP/DEAP calculations	On the NSAI register of Airtightness Testers[23]	Experience of working on traditionally built buildings

There are proposals to create a register for retrofit specialists in Ireland[24], which will hopefully be available in the near future. A register should assist building owners to evaluate the competence of building professionals for retrofit projects.

1.5 THE IMPORTANCE OF CONSIDERING EMBODIED AS WELL AS OPERATIONAL CARBON EMISSIONS

Ireland's current climate targets commit the country to being carbon neutral by 2050. **Globally, buildings account for 39% of total carbon emissions – 11% of which is associated with embodied emissions and the remaining 28% due to the operation of buildings**. Given the outsized emissions from the agricultural industry in Ireland, accounting for 32% of total national emissions versus 11% in the rest of Europe, in 2017 the built environment accounted for only 12.7% of total carbon emissions[25]. This however does not mean that Ireland is performing better than its European counterparts in this sector as **Irish homes use 7% more energy and emit 58% more CO_2eq than the European average[26].** Retrofitting existing buildings will reduce operations emissions, but it will also offset future embodied emissions as less materials will be needed compared to the construction of highly efficient new replacement buildings.

The Climate Action Plan 2019 sets an ambitious target of retrofitting 500,000 existing homes to a B2 Building Energy Rating (or cost optimal equivalent or carbon equivalent) by 2030. In addition, all public sector buildings and one third of commercial buildings are to achieve a BER of B by 2030. The Climate Action and Low Carbon Development Bill 2021 proposes the introduction of sequential five-year carbon budgets for primary sectors, each of which will have to substantially reduce their carbon emissions year-on-year to stay within their allocated carbon budget.

Although neither the current Climate Action Plan 2019 nor the Bill distinguish between embodied and operational emissions, the European Commission acknowledges the importance of reducing embodied emissions in cross-sector supply chains, using the Renovation Wave initiative to expand the construction market for sustainable construction products and services[27]. Embodied emissions are carbon-dioxide equivalent (CO_2eq) emissions resulting from the production, transportation and installation of building materials and components on site. Embodied emissions also include emissions from maintenance, repairs, replacement and ultimately the demolition and disposal of building materials over the full lifetime of the building. Embodied emissions can account for a large percentage of a building's total life cycle emissions, especially if high embodied carbon materials such as concrete, cement mortars, steel, aluminium, PVC products and petroleum-based insulations

[23] See: https://www.nsai.ie/certification/agrement-certification/air-tightness-testing/
[24] Jammet, M. and O'Brien, L. (2020) Developing A Register of Building Professionals & Construction Workers who Have Upskilled In Energy Renovation. Available at: https://www.igbc.ie/wp-content/uploads/2021/01/WP2-D6-D7Final_Master.pdf. List of suitable skills from retrofit professionals: Appendix 9A.
[25] Climate Action Plan 2019, Department of Environment, Climate and Communications: https://www.gov.ie/en/publication/ccb2e0-the-climate-action-plan-2019/ .
[26] Climate Action Plan 2019 to Tackle Climate Breakdown, Department of Communications Climate Action and Environment (2019). Dublin: The Government of Ireland.
[27] Renovation Wave: doubling the renovation rate to cut emissions, boost recovery and reduce energy poverty, Press Release, 2020. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1835

are used in large quantities. In contrast, traditional materials such as lime mortars and renders, timber or native thatch have low associated embodied carbon emissions, especially if locally sourced.

Operational emissions are CO_2eq emissions that result from the day-to-day use of a building through energy consumption. The operational emissions of a building can account for a large portion of the building's life cycle emissions as it is the accumulation of emissions throughout the entire operation of the building.

To make a truly sustainable decision when planning alterations, the whole-life of the building materials should be taken into account through whole-life carbon assessments. A whole life carbon approach allows a building owner to identify the 'best combined opportunities for reducing lifetime emissions, and also helps to avoid any unintended consequences of focusing on operational emissions alone'[28]. The whole-life carbon approach uses Life Cycle Assessment (LCA) to calculate the total carbon footprint of a building project by following the methodology outlined in I.S. EN 15978:2011 *Sustainability of Construction Works – Assessment of Environmental Performance of Buildings – Calculation Methods*. LCA can also incorporate Life Cycle Costing (LCC) which considers all monetary costs associated with the life cycle of the building (e.g. design, construction, operation, maintenance and demolition/recycling).

The lifespan of materials and products is an important consideration when carrying out an LCA. A material or product that can be easily repaired and for which the skills for those repairs exist (e.g. timber framed windows) is more likely to have a longer lifespan than materials or products that are hard to repair (e.g. PVC windows). This assessment is useful when comparing the environmental impact of different materials or products. For example, a natural stone material, such as Irish slate, can have a high environmental impact as it needs to be extracted in quarries, similar to cement products. However, comparative non-natural roofing materials need to be manufactured in factories which increases their embodied emissions. If these materials have similar embodied carbon emissions, it is then useful to look at their lifespan – the one with the longer lifespan and greater re-use potential will be the better choice. The use of more resilient long-life materials will reduce the need to carry out replacements, thus reducing the overall embodied emissions of the building as well as overall cost.

It is also important to note that some materials or systems may have an initially high embodied carbon such as heating systems like heat pumps but provide high operational savings, overall reducing the building's life cycle emissions within its lifespan. Therefore, considering embodied emissions and operational emissions in tandem is the most accurate way of calculating the carbon footprint of a building project.

There are resources available to homeowners and building professionals to help them choose low-carbon products. Environmental Product Declarations (EPDs) are standardised documents used to communicate the environmental performance of a product. While manufacturers are not yet required to produce EPDs for each product, many have commissioned them to demonstrate the sustainable qualities of their products. EPDs can be found online or requested from manufacturers but care must be taken to ensure that the EPD is verified by a relevant authority such as the Irish Green Building Council[29] or the BRE Group[30]. EPDs provide information on a product based on several parameters (see Figure 5 and Figure 6) but for carbon emissions, the important parameter is Global Warming Potential (GWP). GWP is a measure of how much heat a greenhouse gas traps in the atmosphere, relative to carbon dioxide. Carbon dioxide has a GWP of 1, methane has a GWP of 25 and nitrous oxide has a GWP of 265. The GWP in EPDs is measured in CO_2 equivalents (CO_2e). The results are

[28] Sturgis, S. and Papakosta, A. (2017) Whole Life Carbon for the Built Environment, London. Available at: https://www.rics.org/uk/upholding-professional-standards/sector-standards/building-surveying/whole-life-carbon-assessment-for-the-built-environment/.
[29] IGBC EPDs can be viewed at: https://www.igbc.ie/epd-search/
[30] BRE EPDs can be viewed at: https://www.greenbooklive.com/search/scheme.jsp?id=260

presented for selected life cycle stages (modules) (Figure 6), which can then be compared to similar products that are being considered for use. Resources are available to help first-time users to properly read EPDs[31] and tools are currently being developed to make it easier for building professionals to compare EPDs (e.g., the EC3 Tool[32] and the Material Pyramid[33]).

PRODUCT STAGE			CONSTRUCTION ON PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse – Recovery – Recycling potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

Figure 5 The life cycle stages (referred to as life cycle modules) reported in EPDs. EPDs will declare the stages for which stages GHG (greenhouse gas) emissions have been calculated.

LCA Results

Environmental impact per m² of material

PARAMETER	UNIT	A1	A2	A3	TOTAL A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
GWP	[kg CO_2-Eq.]	1.49E+01	1.68E-01	4.43E-01	1.55E+01	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND
ODP	[kg CFC11-Eq.]	9.54E-07	3.08E-08	2.27E-08	1.01E-06	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND
AP	[kg SO_2-Eq.]	6.28E-02	5.60E-04	9.37E-04	6.43E-02	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND
EP	[kg (PO4) -Eq.]	1.28E-02	7.72E-05	2.43E-04	1.31E-02	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND
POCP	[kg ethene-Eq.]	2.82E-02	8.76E-05	8.26E-03	3.65E-02	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND
ADPE	[kg Sb-Eq.]	7.80E-05	4.88E-07	5.85E-07	7.91E-05	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND
ADPF	[MJ]	4.22E+02	2.56E+00	5.51E+00	4.31E+02	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND

GWP = Global warming potential; ODP = Depletion potential of the stratospheric ozone layer; AP = Acidification potential of land and water; EP = Eutrophication potential; POCP = Formation potential of tropospheric ozone photochemical oxidants; ADPE = Abiotic depletion potential for non-fossil resources; ADPF = Abiotic depletion potential for fossil resources.

Figure 6 Example of LCA results in EPDs. For GHG emissions, the important parameter is Global Warming Potential (GWP).

1.6 AVOIDING 'LOCK-IN'

The deep retrofit of an existing building is sometimes not achievable in one go. In fact, if incremental retrofit works are not conducted in a certain order they may create what is known as a 'lock-in effect'. This happens when works are implemented that make it harder or costlier to implement other measures in the future. For instance, when insulating a roof one should consider how this might impact future retrofit works, e.g Would external or internal wall insulation connect to the roof insulation? Will it be possible to install PV or solar thermal panels at a future date? Long-term planning is key to avoid such lock-in issues and to develop a clear, step-by-step retrofit plan.

To assist this process, Building Renovation Passports (BRPs) are being developed as a master plan for the deep energy retrofit of a building. BRPs will empower building owners to undertake deep energy retrofits by providing a set of actions, a sequenced plan and estimated costs, which will help to address the barriers to consumer

31 The Alliance for Sustainable Building Products (ASBP) - https://asbp.org.uk/briefing-paper/epd-how-to-use
32 The Embodied Carbon in Construction Calculator: https://carbonleadershipforum.org/what-we-do/initiatives/ec3/
33 The Material Pyramid: https://vandkunsten.com/en/news/material-pyramid

decision-making by giving building owners the technical information they need to make informed choices. They will also help embed long-term climate goals into the short- and medium-term renovation steps.

The Energy Performance of Buildings Directive (EPBD) 2018/844 refers to building renovation passports as an example of a measure whereby Member States can support targeted cost-effective renovation and staged deep renovation – Art. 2a.1(c). As part of its Renovation Wave initiative[34], the European Commission has committed to launch a proposal on Building Renovation Passports by 2023.

IBRoad, a version of a Building Renovation Passport, was piloted in Ireland in 2020 with support from SEAI. As part of this pilot, the passports were tested on both pre-1900 stone walls and early 20th century solid brick walls[35]. The study also highlighted the importance of hiring qualified building professionals to plan high quality phased retrofits. Although Building Renovation Passports are not yet widely available in Ireland, the principles of the passport should be used where deep retrofit is not possible to create better conditions for staged renovation.

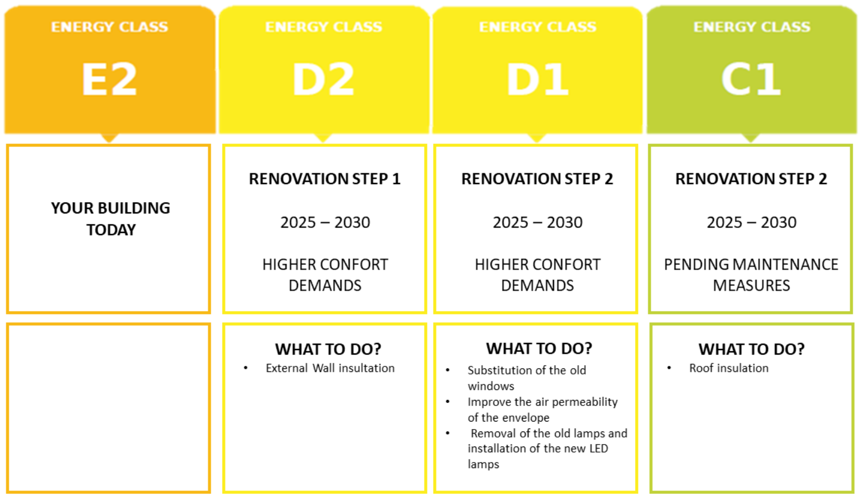

Figure 7 Example of a renovation roadmap developed for an 1877 solid stone wall building.

[34] European Union, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives (2020) European Commission.
[35] Introducing Building Renovation Passports in Ireland - Feasibility Study (2018), Dublin. Available at: https://www.igbc.ie/wp-content/uploads/2020/09/Introducing-BRP-In-Ireland-Feasibility-Study.pdf.

2 UNDERSTANDING HOW TRADITIONAL BUILDINGS WORK

Understanding the building is paramount prior to considering any form of retrofit works. It is important to know the approximate construction date of the building, the materials it is constructed from, and the construction methods used. These basic factors will dictate what can, cannot or should not be done to the building. A fourth factor to consider is the existence of later interventions – have there been inappropriate interventions such as the application of a cement-based render or repointing of brickwork with a cement-based mortar? Has the interior been dry lined? These inappropriate interventions can be detrimental to traditional building fabric, and many will need rectifying prior to implementing a robust energy retrofit.

In a sense, we look after our historic buildings not only for ourselves but for those who come after us. Many of these buildings have been around for generations before us and it is our responsibility as stewards to hand them on in good condition for the enjoyment of future generations. To ensure that the works undertaken do not damage the special qualities of a historic building, it is important to understand some of the basic principles of good building conservation. Many of these are common-sense and all are based on an understanding of how old buildings work. Before you start any conservation or retrofit project, **learn as much as you can about your particular building**. What is its history? How has it changed over time? Remember that **later alterations may be important too** (if not detrimental to the building fabric) as evidence of its layered history.

In this chapter, methods for assessing the factors that affect a traditional building's thermal performance and energy efficiency are presented as well as how these factors may be affected by climate change. Guidance on retrofit measures typically suitable for traditional buildings is provided in Section 3.

2.1 TRADITIONAL BUILDING PHYSICS

2.1.1 *THERMAL MASS AND HEAT STORAGE/LOSS*

Different materials absorb and radiate heat at different rates. Thermal mass is the ability of high-density materials such as brick and stone to absorb heat, retain it and then release it again slowly over time (termed thermal inertia), helping to moderate the temperature fluctuations within a room (decrement delay). A thermally lightweight structure responds very quickly to solar gain or heating but is less effective in storing energy for use later, which can result in larger temperature swings within a room.

Depending on the orientation and size of the windows in a building, the use of passive solar gain is improved in buildings that have a high thermal mass, arising from their overall construction. For example, masonry external walls allow a building to absorb, retain and later release the heat absorbed from the sun.

It should be noted that a heavy masonry wall and a well-insulated lightweight structure with the same U-value (rate of heat loss) have very different responses to internal space heating. Traditional buildings with a high thermal mass have a relatively slow response time which can be seen as advantageous. External insulation preserves and enhances thermal mass effects, internal insulation degrades them. The effects of thermal mass on energy use are included in the NEAP/DEAP calculation.

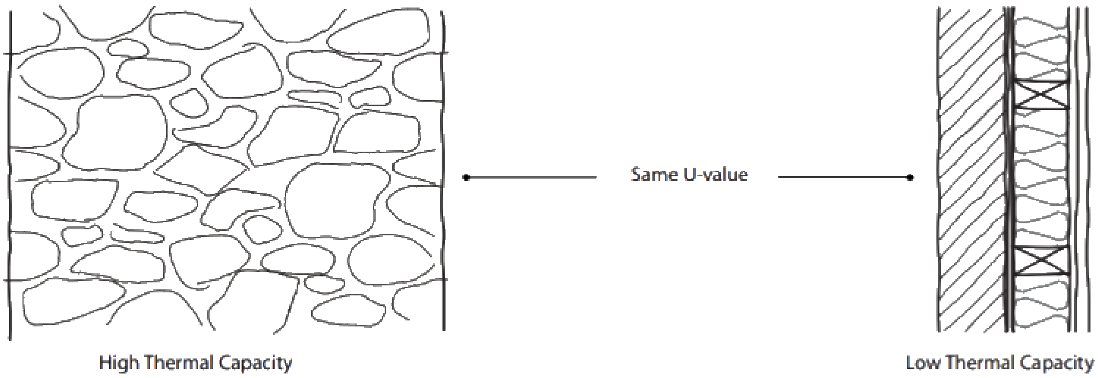

Figure 8 Two different wall constructions with similar U-values may have very different thermal masses.

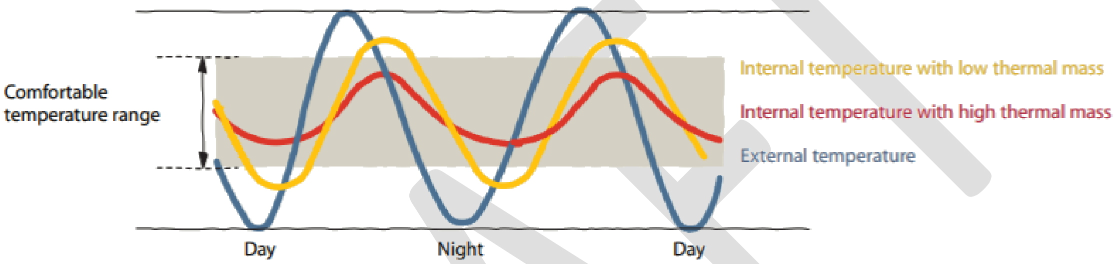

Figure 9 A graph showing the summertime temperature changes within buildings with high thermal mass (red line) and with low thermal mass (yellow line). As can be seen by the red line, less extreme changes of temperature are experienced inside the building with the higher thermal mass.

Heat loss from the interior of a building mainly happens in two ways - by transfer (conduction) through the materials that make up the external envelope of the building (measured as a U-value) or by the exchange of air between the interior and the exterior environment that is, ventilation and/or air leakage/infiltration. In traditional buildings, the highest percentage of heat is typically lost through the walls (35%), followed by the roofs (25%), floors (15%) and windows (10-15%).

Heat is transferred through different building elements as it goes from warm areas to cold areas. Each building element has its own rate of heat transfer, described by its U-value. The U-value (discussed in further detail in Section 2.2.6) is a measure of the rate of heat transfer through a building element. The slower the heat travels through a material, the better an insulator it is and the lower the U-value. For any given construction, independent of U-value, heat loss is also directly related to the temperature difference between the exterior and interior environments, and, to a lesser degree, the colour and texture of the building elements (although this last element is of lesser significance than material thermal conductivity).

Increased moisture in the building fabric reduces its ability to insulate and leads to a faster rate of heat loss. As a result, the effective U-value of the fabric increases. Common causes of moisture ingress include damp penetration in walls due to defective or removed render, leaking gutters, cracked sills, poorly fitting windows frames and defective chimneys. Plant growth in walls and chimneys is also a common cause of moisture ingress. **It is therefore important to ensure that buildings are in good condition and sources of water ingress or damp are rectified before insulation is added to achieve improved U-values.**

2.1.2 *MOISTURE MOVEMENT*

Moisture movement through the building fabric occurs via a number of mechanisms. Convection, discussed earlier under air infiltration, can carry significantly more moisture into and through the building fabric than any other means of moisture and vapour transport, hence the importance of fabric airtightness, especially at junctions where structural connections of timber elements may be present, e.g., wallplates or joist ends. Other common mechanisms for moisture transport are vapour diffusion and capillary action. Diffusion occurs when vapour is transferred across materials and boundaries from an area of high vapour pressure to an area of low vapour pressure via a natural existing vapour differential. Capillary action is the movement of water and vapour molecules through the porous structure of materials. The size and shape of pores has a significant impact on the movement of vapour through materials. Some constructions also make use of natural capillary breaks to control the passage of moisture in the construction.

In traditional buildings which often have highly absorptive external faces, e.g., brick, it is common for driving rain to penetrate the outer layer and move into the building from outside to inside, sometimes aided by solar gain on this same façade providing the thermal energy to increase the vapour pressure differential. This is often why it is important to maintain the vapour permeability of the construction towards both inside and outside. Capillary action can also work against the force of gravity, such as the case of rising damp in an external wall. Many traditional buildings will not have a functioning damp proof coursing (DPC), meaning there is a naturally occurring transfer of moisture from the ground level into the lower section of the wall. Where such a building has had a relatively vapour-tight layer applied at some point, e.g. cement render or gypsum plaster with vinyl paint, it is common to see vapour pressure on these layers causing debonding and paint bubbling. In such cases the removal and replacement of these layers is necessary with vapour permeable materials, such as insulating lime plaster, lime plaster, or vapour permeable insulating products such as wood fibre or calcium silicate boards and their proprietary finishing systems. It is important that any moisture ingress issues are addressed before insulation is added.

Figure 10 An example of a consequence of poor moisture movement through building fabric. Materials which trap moisture can increase the risk of mould growth.

The diagrams below demonstrate maintenance and material alterations that lead to moisture accumulation and retention in external solid walls.

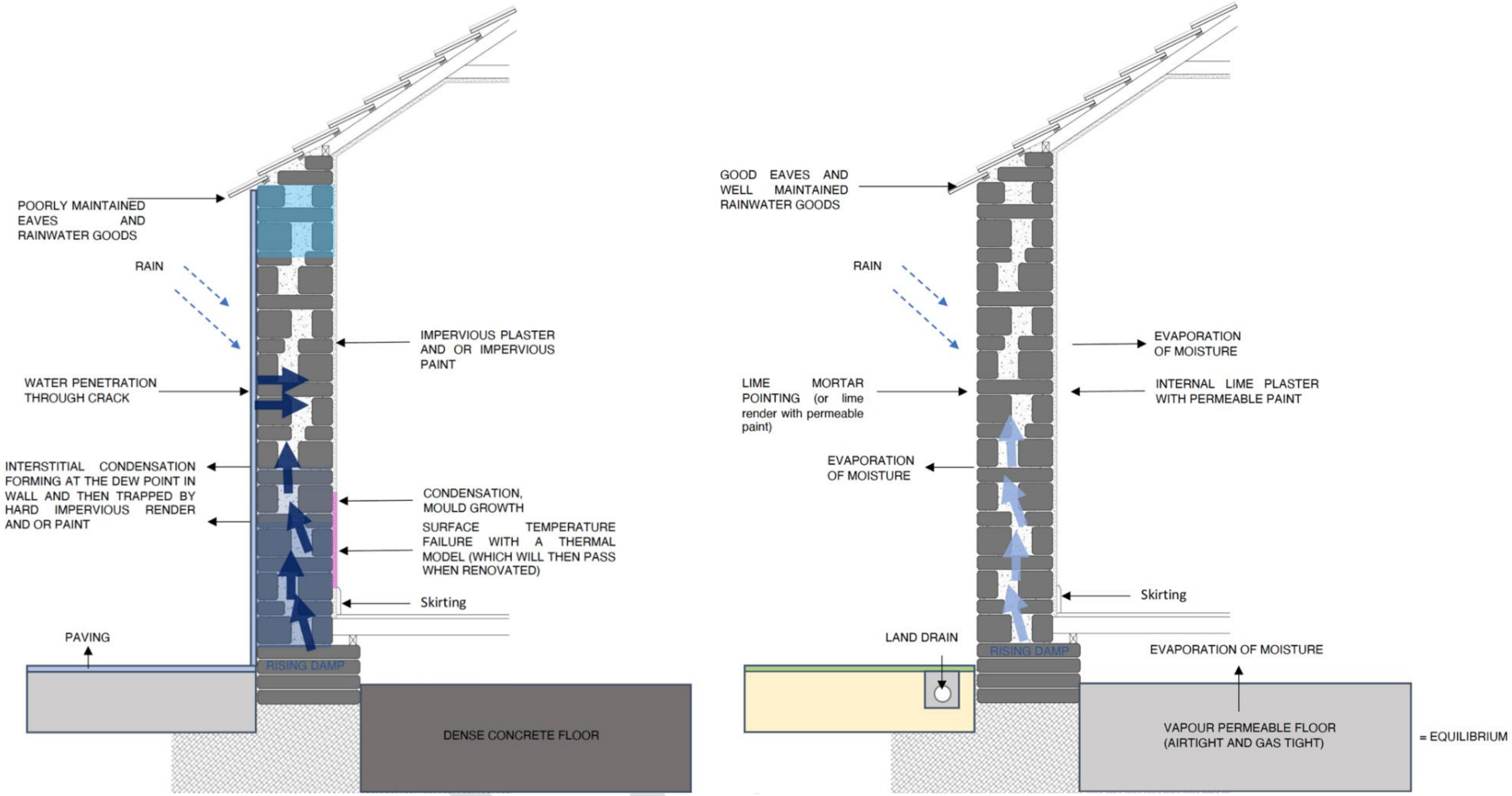

Figure 11 Traditional solid wall threatened by impervious modifications and poor maintenance versus a well-maintained solid wall that achieves acceptable moisture balance.

2.1.3 *THERMAL BRIDGING*

Thermal bridging is described as any area in which the otherwise uniform flow of heat from the warm to cold side altered due to changes in the fabric area, changes in material properties or penetrations of the thermal envelope. In simple terms, for a square metre area of any wall, the internal and external areas are the same and heat flow is therefore perpendicular to the internal surface, providing the path of least resistance for heat flow. Where two walls meet at a corner however, although the construction of the wall itself may be perfectly continuous, the outer wall area is now greater than the inner wall area, allowing more heat out than is being put into the wall. This constitutes a thermal bridge as the flow of heat is no longer perpendicular to the inner surface. This shape creates an increased heat flow through the wall abutment junction, which in turn leads to reduced temperatures at the corner than on the adjoining wall areas

Figure 12 Thermal image showing thermal gaps at junctions.

The additional heat losses at junctions of building elements, whether resulting from discontinuity of insulation or geometry, are called *linear thermal bridges* and are described by linear psi-values, measured in Watts per meter-Kelvin (W/mK).

Thermal bridges can also be caused by penetrations through the thermal envelope, such as steel beams or timber joists. Where the penetrating element has a higher thermal conductivity (W/mK) than the building element which it penetrates, the heat flow local to the penetration will be higher than through the building element generally. Heat losses from single point penetration of the envelope are called *point thermal bridges* and are described by chi-values, in units of Watts per Kelvin (W/K).

Thermal bridging can in no case be completely avoided, however many steps can be taken to reduce additional heat losses from thermal bridging and to therefore increase the internal surface temperatures at these locations (discussed further in Sections 3.3 - 3.6).

2.1.4 *AIRTIGHTNESS, VENTILATION AND INDOOR AIR QUALITY*

As more emphasis is put on improving the insulation and airtightness of traditional buildings, greater attention and care needs to be given to ventilation and indoor air quality. Airtightness, ventilation and indoor air quality are interdependent, and each building retrofit plan should address them as such.

A greater focus on airtightness has in part been driven by the requirement for major renovations to comply with Technical Guidance Document Part L of the building regulations, which stipulates an upper limit to acceptable air permeability ($m^3/m^2.hr$). Greater airtightness can lead to an improved BER due to reduced heat losses from infiltration, which is also desirable. What is often overlooked is the necessity of airtightness to prevent the movement of moist air via convection through the building fabric or at interfaces between building elements.

Contrary to popular belief, leaky construction is not an inherent feature of traditional buildings but a consequence of old age due to shrinkage, settlement, alterations and repairs, wetting/drying cycles and occupants' actions all inducing cracks and creating air pathways. Traditional construction is capable of achieving the highest levels of airtightness without danger to the building fabric. In fact, traditional diffusion open materials like wet lime plaster is capable of achieving a satisfactory level of airtightness and also reduces interstitial condensation. The annual application of lime wash, ritualised in many rural communities, was an effective means to reinforce the external airtight layer to traditional Irish cottages.

Airtightness is an important consideration when installing any type of insulation as the effectiveness of insulation can be reduced if heat can simply escape through gaps in the building envelope and bypass the insulation, a process known as thermal bypass. Furthermore, when warm air is allowed to leak out, the moisture therein can be carried to colder parts of the building fabric where it may condense, leading to moisture build-up and increased risk of long-term damage to the building fabric. It is therefore important that airtightness improvements are included in every retrofit project.

Although airtightness testing is highly recommended for all retrofit projects, it does not determine whether the air leakage is occurring evenly across the entire fabric, thus reducing the risk in any one area, or whether the majority of the measured air leakage is occurring at a particular location that has been overlooked in the retrofit plan or has simply been badly sealed. For this reason, it is highly recommended that leakage testing is carried out as well by an experience NSAI-accredited airtightness tester or equivalent using a smoke machine or micro anemometer. Thermal imaging can also help to pinpoint exactly where leaks are. Once leak locations are identified, these can be sealed during the airtightness test with the effect measured instantly.

When a traditional building is made more airtight as a result of retrofit measures - which can be expected to occur when window seals are repaired, roof and floor insulation is installed, and chimneys are blocked from use - adequate controlled ventilation must be introduced and maintained. Ventilation is the purposeful supply of fresh outside air and the removal of stale indoor air to or from spaces in a building. The purpose-provided ventilation may be provided by natural or mechanical means and is a controlled exchange of air as opposed to uncontrolled movement of air through gaps and cracks in the building fabric. The ventilation system (mechanical or natural) should be capable of providing satisfactory indoor air quality for occupants at all times.

TGD Part F states that adequate and effective means of ventilation shall be provided by:

a) limiting the moisture content of the air within the building so that it does not contribute to condensation and mould growth, and
b) limiting the concentration of harmful pollutants in the air within the building.

In addition to providing a healthy indoor environment, adequate ventilation and the removal of excess indoor moisture is important to protect the building fabric. Internal temperatures and relative humidity levels are directly related in that increasing temperature will decrease relative humidity and vice versa (with a constant moisture load). This is why it can be common to see condensation issues in buildings which are under-heated. The under-heating of buildings is more typical in inefficient buildings since the energy (and thus cost) required to maintain acceptable internal temperatures is higher. This increases likelihood of energy poverty and persistent cold and damp conditions will likely have an impact on the long-term health of the building fabric as well as on the health of occupants.

TGD Part F provides guidance on purpose-provided ventilation for all buildings with an air permeability of $5m^3/(h.m^2)$ at 50pa or less. Where airtightness is likely to be less than $5m^3/(h.m^2)$ at 50pa, ventilation must be introduced through:

a) Background ventilation: A secure ventilation opening generally located in a wall or window for the purpose of provision of general ventilation, generally incorporating a controllable ventilation grill, which can be fully closed.

b) Purge ventilation: Ventilation by means of a large adjustable ventilation opening or openings, which will allow the movement of a substantial volume of air in a short time period e.g., an opening window or door, and with some part of the ventilation opening at least 1.75 m above the floor level.

c) Extract ventilation: Designed provision for the removal of air from a room or space directly to outside. Extract ventilation may be provided by natural means (e.g., passive stack ventilation) or by mechanical means (e.g. by an extract fan).

Where airtightness is less than $3m^3/(h.m^2)$ at 50pa, mechanical ventilation is required. Recent EPA research has also indicated that Radon levels in very airtight buildings can be effectively managed through balanced mechanical ventilation capable of inducing a slight positive internal pressure.

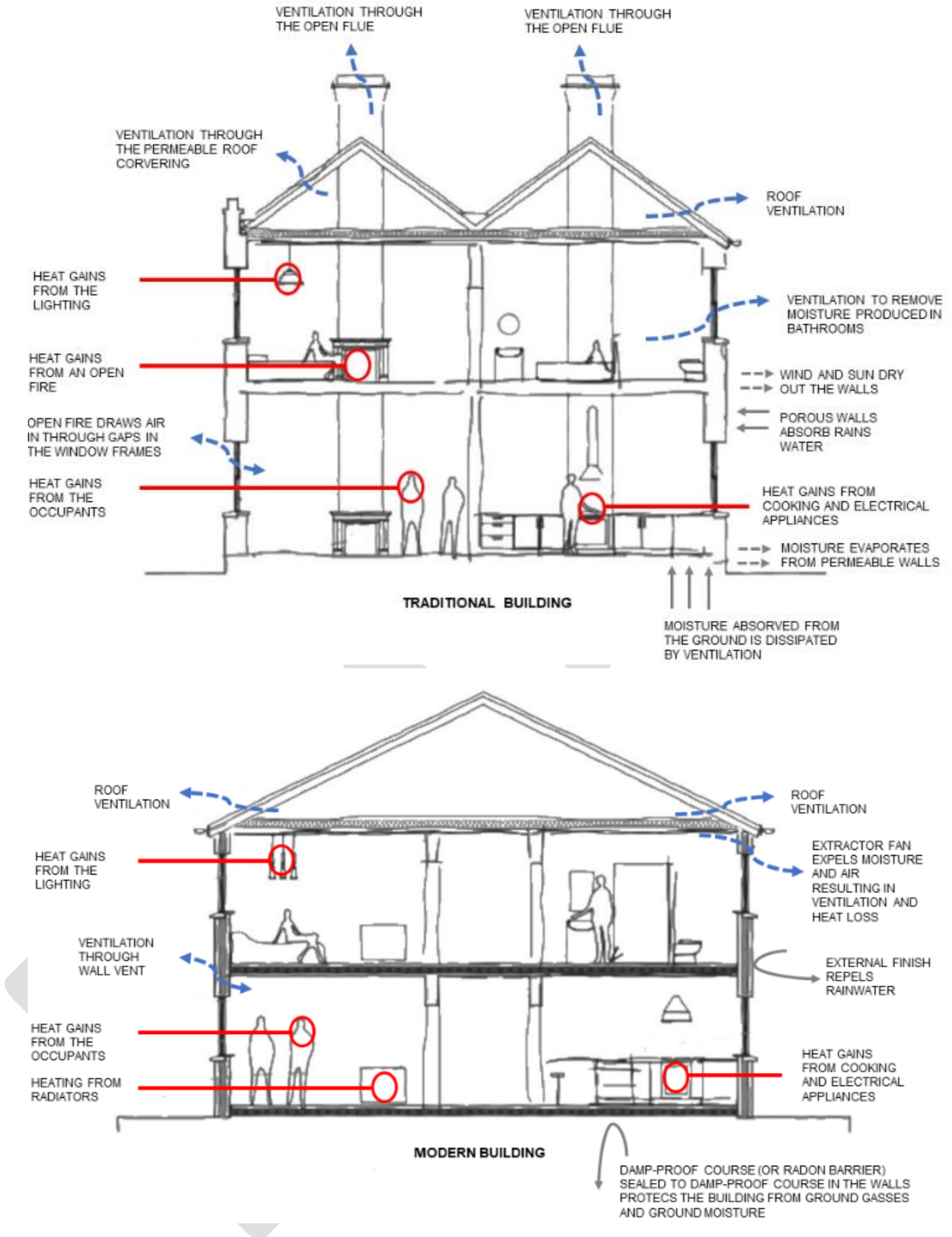

Figure 13 A comparison of the ventilation and heating requirements for a traditional building (top) and a modern building (bottom).

Indoor air quality (IAQ) is reaching a new level of importance and attention due to the unintended consequences of increased airtightness in new and existing buildings. Without adequate ventilation, increased airtightness can lead to a build-up of unhealthy levels of moisture and other indoor airborne pollutants.

The sources of indoor air quality issues are manifold, but primarily include elements produced directly by occupants (e.g. heat, carbon dioxide and humidity), elements produced within the building from activities or materials (e.g. heat, moisture, combustion gases, cooking fumes, off-gassing from new furnishings, carbon monoxide, volatile organic compounds (VOCs), Particulate Matter PM2.5, mould spores, mites and microbes), and elements produced externally that are introduced into the building (e.g. VOCs, PM2.5, ozone, nitrogen dioxide -NO2, and pollen etc). Many of these elements are odourless and colourless and not perceptible to most people, nevertheless they can negatively impact occupant wellbeing as well as the building fabric. For further information, the World Green Building Council provides guidance on the many sources of indoor air pollution and possible solutions[36].

Indoor Air Quality can be assessed using a number of IAQ monitors on the market and it is recommended to undertake the assessment while the building is in occupation to register the full effects of human made pollutants. The assessment should also be done before any retrofit works take place to establish a baseline and to understand current and potential future IAQ risks.

The provision of ventilation and maintenance of good indoor air quality requires careful planning and consideration, and in consequence, **a ventilation system designed and installed in compliance with TGD Part F should be considered as part of any retrofit strategy**. Where mechanical ventilation systems are provided, these should incorporate control indicators to indicate to the occupant that the system is operating correctly and advise when a fault has occurred. Control indicators should be in a visible location to the occupant and not in a remote location such as in the attic or above the ceiling.

Finally, it should be noted that with Protected Structures, the addition of openings in walls or vents to windows, doors or roofs may not be acceptable and planning permission may not be granted. In these cases, well designed mechanical ventilation may provide a solution. Guidance should be sought from the local Conservation Officer with regard to the ventilation options in Protected Structures before any works are commenced.

2.2 PERFORMANCE ASSESSMENT METHODS

There are a number of non-destructive techniques available to assess the energy efficiency of an existing building. These range from the use of simple handheld devices such as moisture meters and borescopes to more complex and expensive methods such as thermal imaging. Expert knowledge and experience will be needed to decide which assessment method is appropriate in a particular case, to undertake the assessment and to interpret the results. A contractor experienced with traditional buildings or a conservation expert should be able to advise on the assessment methods required.

2.2.1 *THERMOGRAPHY*

Thermography, or thermal imaging, is photography using a camera that captures infra-red (IR) light rather than the visible light captured by a standard camera. IR light occurs beyond the red end of the visible light spectrum and is invisible to the naked eye. All objects that are warmer than absolute zero (-273°C) emit IR light. The warmer the object is, the more IR light it emits. IR cameras record the amount of IR light emitted by an object and translate it into a temperature which is indicated on a scale bar adjacent to the thermal image or thermogram. Even very small temperature differences, as low as 0.1°C, can be recorded by IR cameras. The image produced by an IR camera is multicoloured with each colour representing a different temperature. Different colour scales can be used depending on the objects photographed. Thermography has many varied

[36] Air Quality in the Built Environment, World Green Building Council. Available at: https://worldgbc.org/clean-air-buildings/solutions

applications in different disciplines and can be a useful tool when assessing the condition of a building. It has particular advantages for investigating historic buildings as it is a non-invasive, non-destructive method.

Thermal imaging can be used to identify potential problems with a building's fabric. When looking at traditional buildings, thermal imaging might be used to identify areas of dampness and to locate thinner depths of wall, cracking and voids. Expertise is required both in deciding how and when to take IR images and later in interpreting the information. For example, objects which have high or low emissivity such as metal do not give an accurate temperature reading. Weather conditions, orientation and the time of day when the image was taken all have the potential to affect the reading. The information gathered from thermal images can be properly assessed only in conjunction with data gathered as part of a comprehensive condition survey.

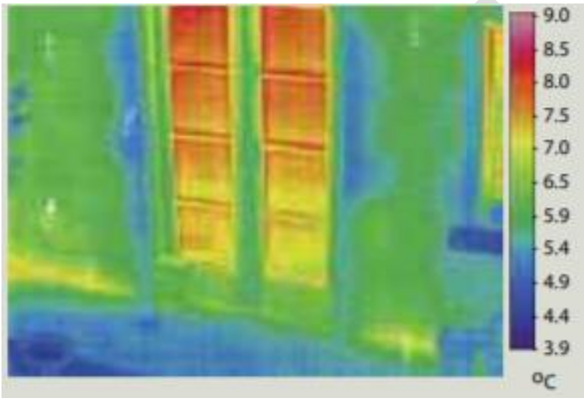

Figure 14 A thermographic image of a double-glazed door at semi-basement level in a nineteenth-century terraced house; note how the yellow patches at the base of the wall, which are damper, indicate that these areas are emitting heat at a higher rate than the rest of the wall.

2.2.2 *Air Leakage Testing*

Air leakage testing, or fan-pressurisation testing, assesses the airtightness of a building and the rate of air leakage occurring through the fabric. Testing a building's airtightness may highlight areas or points of particularly high uncontrolled air leakage which could be remedied without compromising the long-term health of the building fabric. Care should be taken when undertaking air-pressure tests on older buildings which contain fragile building elements, including delicate glazing bars and thin, hand-made panes of glass which would be damaged if subjected to excessive pressure.

2.2.3 *Endoscopy or Remote Visual Inspection*

Inspections of concealed parts of a building's construction can be carried out using a borescope or fibrescope camera, generally with minimal disruption to the building. This type of inspection can be used to investigate walls, roofs and floors for hidden defects by inserting a borescope or fibrescope into a small inspection hole. In a protected structure, the drilling of an inspection hole should be carried out with care and a location should be chosen that avoids any adverse impacts. In some cases, drilling through the building fabric may be unacceptable.

Such an inspection can be used as a follow-up to a thermographic survey to investigate the exact cause of heat loss through a particular part of the building fabric. The results of the inspection can be photographed or videoed on a camera attached to the system.

2.2.4 *RADAR*

Examination of a building with radar uses low-power radio pulses to determine the make-up and condition of a structure. It can be used successfully on most construction materials to locate and measure voids, cracks, areas of corrosion and discontinuities in walls or floors and to detect the presence of old chimney flues. The use of radar is a relatively expensive and complex assessment method that requires expertise to undertake and to analyse the resulting data.

2.2.5 *ULTRASOUND*

Ultrasonic scanning involves the use of high-frequency sound waves to provide a cross-section through a material. It can be used across very fragile surfaces without causing damage, which makes it particularly week suited for use on sensitive historic buildings. This non-destructive technique can be used to determine if there is any decay present in structural timbers and, if so, its extent. It can also be used to assess the structural integrity of timber joints and the presence of zones of weakness within stone blocks. A high level of skill and experience is needed to carry out the assessment and interpret the results.

2.2.6 *CALCULATING U-VALUES*

U-values are used to describe the thermal performance of building elements and are part of the base data used to assess the energy performance of whole buildings.

To calculate the U-values of modern building elements, the material characteristics of a building element are required. Modern building elements usually have a series of layers, each with a known thermal conductivity, making the calculation of U-values using validated software relatively straightforward. Numerous software packages exist to do just this but further guidance on calculating U-values and a list of default values for common building materials can be found in Appendix A of Technical Guidance Document Part L.

In general, the first step is to establish the thermal conductivity k (W/mK) of each material in the construction using certified material data. Manufacturers should provide certified data in compliance with Construction Product Regulations and Technical Guidance Document Part D.

Next, the thermal resistance of the material layer is calculated - using the following formula:

> R (m^2K/W) = d/lambda, where d(m) is the thickness of each material and the lambda value is the thermal conductivity (W/mK). The U-value of a building element made of multiple layers is given by: U = (W/m^2K).

As U-values are calculated based on a notional fixed temperature difference of 1K between inside and outside, they remain constant for a given type and thickness of material; the U-value does not normally take into account orientation or exposure, although a heat balance calculation of overall heat losses (losses versus gains) for windows gives radically different values depending on whether a window is north or south facing. While overall heat loss calculations can be adjusted for emissivity (the extent to which a body reflects or radiates heat) of the internal and external surfaces, it is more difficult to adjust calculations for material defects or climate variations (such as a chilling wind), both of which increase the rate at which heat is lost through a building's fabric envelope. The combination and proportion of materials (e.g. lime mortar versus stone) will also affect the thermal efficiency of the wall and a general estimate is usually made when inputting information into U-value calculation software.

Where a more accurate U-value assessment is required, in-situ U-value measurements using heat flux sensors in accordance with ISO 9869-1:2014 can used to more accurately determine the thermal performance of traditional walls. Research on U-values has shown that software programmes for U-value calculation tend to underestimate the thermal performance of existing structures compared with the results from in-situ measurements.[37] It should be noted however that in-situ U-values are currently not an acceptable source of data for demonstration of compliance with TGD Part L for major renovations and hence cannot be used to calculate the Building Energy Rating.

Figure 15 In-situ U-value measurement kit installed on the internal face of a wall.

2.3 POTENTIAL HEALTH RISKS

It is important to consider how the building fabric and systems may be affecting the health of the occupants. Poor retrofit measures can exacerbate already existing issues, which is why it is important to determine what the issues are before intervention. Mould growth, radon and asbestos are three important factors to consider, however, there are other sources of indoor air contamination that may need to be considered.

2.3.1 *MOULD GROWTH*

High levels of relative humidity within a building can arise from external ambient conditions or can be produced by the occupants of the building. Any activity which generates moisture such as cooking, showers and clothes-washing can increase indoor humidity levels. Persistent high humidity levels can result in condensation and mould growth, particularly in poorly ventilated or unheated parts of a building, which can have significant negative impacts on occupant health. Mould growth in buildings depends on many factors, including internal temperature, external temperature, relative humidity, and a building's design and construction. Mould growth can be expected to occur where conditions of 80% relative humidity occur on a surface which can support mould growth within a period of 3-5 days. Given that mould requires certain conditions to grow, to a large extent the

[37] Baker, 2011, Technical Paper 10: U - values and Traditional Buildings - In Situ Measurements and their Comparisons to Calculated Values

risks can be minimised proper management of a building. Relative humidity can usually be regulated with adequate heating and appropriate ventilation, or where required through the use of mechanical dehumidifiers.

As internal surface temperatures are typically lower at thermal bridge locations, the first signs of mould growth are typically seen at these locations. Compounding with any deficiencies in the building fabric, air movement is also typically lower at internal corners and behind curtains, built-in furniture, shutters, etc. A reduction in warm air convection across a surface lowers the surface temperature in these locations compared to the more exposed planar elements around them which creates a cooler place for moisture to condense. At point thermal bridge locations, the thermal bridge effect itself, without any reduction in convection across the internal surface, can be sufficient to lead to mould growth and/or surface condensation.

Figure 16 Mould growing behind shutters.

Figure 17 Extreme case of mould growth.

Some materials do not support the growth of mould, and some indeed resist mould growth by virtue of their pH, e.g., lime plaster. Where a material does not support mould growth, it is still possible that internal surface condensation (i.e., water formation) can occur at the surface where 100% relative humidity is reached. This is commonly seen on single glazed windows in traditional buildings and can lead to the degradation of adjacent materials such as timber glazing bars, window boards, plaster and skirting/mouldings.

To reduce the risk of mould growth and surface condensation as part of a complex or high risk retrofit works, it is recommended to carry out thermal and hygrothermal assessments of the junctions and planar elements. Thermal bridge assessment is carried out in accordance with IS EN ISO 10211 & BR497 – Linear thermal transmittances and temperature factors – calculation conventions. The model can determine total heat flow through a section of the building envelope, which can then be used to calculate the additional heat loss at the junction, as well as measuring internal surface temperatures.

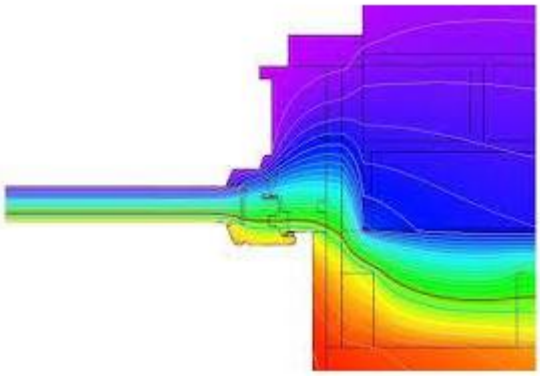

Figure 18 Thermal bridge modelled in analysis software.

Whilst liner thermal bridge models can predict instances of surface condensation, they cannot be used to determine the risk of interstitial condensation. Interstitial condensation occurs when water condenses within a building element when warm moist air hits a cold surface within the thickness of a building element and produces 100% relative humidity condition. This can only be predicted via interstitial condensation risk analysis in accordance with IS EN ISO 13788[38], or hygrothermal analysis in accordance with IS EN ISO 15026.[39]

In complex situations where it is not possible to reduce thermal gaps (for example, when internal wall insulation cannot be wrapped around the window reveal because the shutter boxes are historic and cannot be removed), then thermal modelling is required to prove that any thermal gaps do not present an increased risk of mould growth, resulting in a new or greater contravention of the Building Regulations.

2.3.2 *RADON*

As buildings, in general, tend to have a slightly lower indoor air pressure compared to that in the ground, soil gases, such as radon, can be drawn up from the ground into the building. Ingress routes for radon gas are usually cracks and holes in floors and walls, and gaps around service pipes and cables. Radon from domestic water and gas supplies and from building materials can also contribute to the indoor radon concentration in a building, but in most cases the contribution is considered minor when compared to the soil gases in the ground on which the building is constructed.

Radon testing before and after the retrofit of a building is recommended. A map of radon hotspots in Ireland can be used to indicate a potential risk[40], but high radon concentrations in buildings are not limited to these areas and it is highly recommended that radon testing be carried out as part of any retrofit project. Radon tests are inexpensive and it is hugely important to ensure that radon levels remain at a safe level post-retrofit. The procedure for monitoring radon in homes and workplaces can be found in EPA guidance[41].

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[38] I.S. EN ISO 13788:2012 Hygrothermal performance of building components and building elements
- Internal surface temperature to avoid critical surface humidity and interstitial condensation -
Calculation Methods (ISO 13788: 2001)

[39] I.S. EN 15026:2007 Hygrothermal performance of building components and building elements – Assessment of moisture transfer by numerical simulation

[40] Radon Map, EPA: http://www.epa.ie/radiation/radonmap/

[41] EPA Protocol For The Measurement Of Radon In Homes & Workplaces, 2019: http://www.epa.ie/pubs/advice/radiation/Measurement%20Protocol%20Homes%20and%20Workplaces_May%202019.pdf

Where an initial test indicates a radon level above the 200Bq/m^3 (houses) or 300Bq/m^3 (workplaces) national reference level, a radon control strategy should be included in the retrofit design strategy. Appropriate radon control measures could include:

Ground floor

- Sealing the ground floor slab where a slab-on-grade is present, or
- Increasing the sub-floor ventilation rate where a raised floor is present, or
- Providing a fully sealed membrane and standby radon sump in any new floor installed. In this case, a fully sealed impermeable membrane, described in TGD Part C, is required to ensure that any gas present does not travel up into the house.

Basements

- Where these are unheated, increasing the ventilation rate in the basement is effective.
- In occupied basements where both the floor and a portion of the walls are below ground, specialist design input may be required.

Ventilation

- When closing off chimneys or increasing airtightness, ensure that a ventilation system is installed in accordance with TGD Part F to allow adequate dilution of radon gas.

Walls

- As membranes cannot be taken across walls to ensure a continuous radon barrier over the whole footprint of the building, the best that can be achieved is a reasonably airtight internal coating of the ground floor walls which is then sealed to the floor. Lime plaster is likely to be a sufficient airtight coating in most instances. Note that all walls, including walls previously un-plastered internally, will need to be plastered to form a sufficient barrier to the passage of radon into the building. Impervious coatings to walls should be avoided on traditional vapour permeable walls.

It is not possible to predict the efficacy of any particular radon control measure, therefore radon testing, before and after the renovation works are complete and when the building is fully occupied, is the only reliable way to establish the radon exposure levels of occupants. Further guidelines on dealing with radon in a building are provided in the Technical Guidance Document C: Site Preparation and Resistance to Moisture[42].

2.3.3 ASBESTOS

Asbestos is a term used for the fibrous forms of several naturally occurring minerals which have bene linked to an increased risk of lung cancer and cancer within membranes in the body (mesothelioma). Asbestos has been used in building materials and consumer goods, particularly to resist heat and to give fire protection, and can still be found in many older buildings. Common uses in the past include but are not limited to:

- Insulation lagging in buildings and factories, on pipework and for boilers and ducts.
- Asbestos insulating boards used as wall partitions, fire doors, ceiling tiles, etc.

[42] Technical Guidance Document C: Site Preparation and Resistance to Moisture (2020), Dublin: Department of the Environment, Heritage and Local Government. Available at: http://www.housing.gov.ie/housing/building-standards/tgd-part-c-site-preparation-and-resistance-moisture/technical-guidance-0.

- Asbestos cement products such as sheeting on walls and roofs, tiles, cold water tanks, gutters, pipe and in decorative plaster finishes.
- A spray coating on steel work, concrete walls and ceilings, for fire protection and insulation.

Asbestos materials can be inadvertently disturbed during the maintenance, repair or refurbishment of a building. Drilling, cutting or other disturbance of existing asbestos materials can release asbestos fibres into the air. The presence of asbestos fibres in finished products is not obvious, and the different types of asbestos cannot be distinguished by their visual appearance or colour. Laboratory analysis is required to identify the type of asbestos. If a building does not have any record of asbestos checks or is derelict, it will be necessary to liaise with an asbestos monitoring/surveying company. The EPA website provides information on what to do if there is a suspected presence of asbestos in a building[43].

Some typical places where asbestos can be found are shown below but it should be noted that this does not show all possible uses and locations of asbestos-containing materials. A detailed survey will be required to identify all asbestos-containing materials present in a building.

Figure 19 Examples of where asbestos can be found – panels of corrugated roof sheeting, floor tiles and roof tiles.

2.4 SUSTAINABLE DESIGN PRINCIPLES

Sustainable or passive design means ensuring that the fabric of the building and the spaces within it respond effectively to local climate and site conditions so as to maintain comfort for the occupants with the minimal use of energy. In new buildings this can be taken to its ultimate state where buildings are so well insulated and sealed against uncontrolled air infiltration that no heating systems are required. For a number of reasons, this is neither achievable nor indeed desirable for traditionally built buildings. Nonetheless, it is obvious that past generations of builders had an inherent understanding of the thermal behaviour of a building in its setting. Traditional buildings often portray many of the principles of modern passive design in their location, orientation and overall design.

[43] Asbestos, EPA. Available at: https://www.epa.ie/waste/hazardous/asbestos/

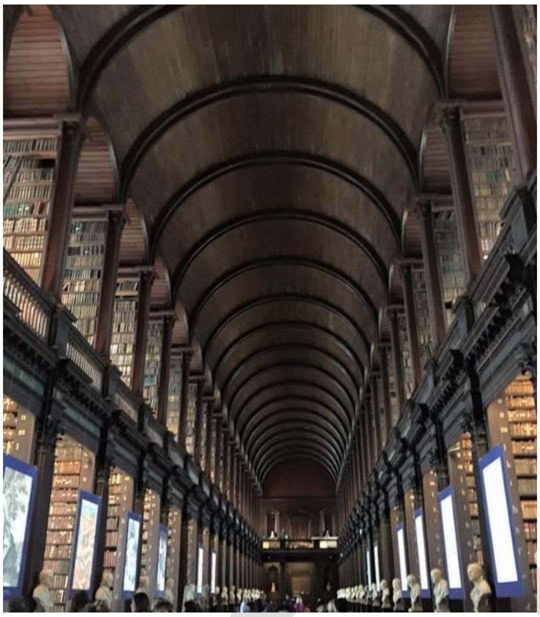

Figure 20 Trinity College Old Library, Dublin. There were never fireplaces in the library, to avoid the risk of fire breaking out. Sunlight streams in through large single-glazed south-facing windows, maximising solar gain. Appropriate steps should be taken to protect light-sensitive historic furnishings and contents from damage caused by both ultra-violet light and visible sunlight.

The following sections present different sustainable design principles which can improve the thermal performance of a traditional building.

2.4.1 *EXPOSURE TO WIND*

Depending on a building's exposure to wind, the rate of heat transfer can be increased when wind blows across the external envelope. Essentially, the windier the location, the greater the heat loss. While the direction of wind always changes, knowledge of prevailing winds can help to determine where the problem areas are. The importance of achieving shelter from cold and damp wind has traditionally been understood; the traditional selection of a location for a dwelling was often in the lee of a hill and, equally importantly, not in a hollow prone to frost. Where natural features did not provide sufficient protection, shelter belts of trees were often planted.

Creating shelter on a site can reduce heat loss and reduce the wind chill factor for people outdoors (though this is not included in the DEAP/NEAP calculations). Notwithstanding any shading they may confer, a permeable barrier such as a stand of trees may be effective at reducing wind speed.

Protection by a stand of trees (with 40-50% permeability) can provide protection for up to seven or eight times the height of the trees[44]. Shelter belts with under-planting, positioned perpendicular to the direction of the prevailing wind, can offer protection for up to 25 times the height of the trees provided that the shelter belt is at least 15 times as long as it is high. When the direction of the prevailing wind is taken into account an optimum orientation can be identified.

Nationally, Ireland's prevailing wind direction is between south and west, and annual average windspeeds are higher within 8km of the coast, with the west coast experiencing higher average windspeeds than the east coast.

[44] The Climatic Dwelling: An Introduction to Climate-Responsive Residential Architecture, Eoin O. Cofaigh, John A. Olley, and J. Owen Lewis of the Energy Research Group, University College, Dublin. 1996.

There is also a significant difference between windspeeds in rural and urban environments, with urban environments experiencing lower windspeeds and higher air temperatures. In terms of orientation, the traditional response and optimum arrangement was to orientate houses so that a gable faced the direction of the prevailing wind, an optimum arrangement; the least effective orientation for a building, from a thermal efficiency point of view, is when the main walls are at a 45 degree angle to the prevailing wind because the wind flows along the length of the wall, thereby cooling it, rather than rising over it (Figure 21.

Figure 21 Most optimum (left) and least optimum (right) orientation of a building to prevailing winds.

2.4.2 *EXPOSURE TO RAIN*

The construction, materials, and exposure of a wall to rain can affect the level and depth of dampness within it. In traditional buildings, the thick solid masonry walls were designed to provide a sufficient barrier to the moisture, allowing drying to occur before the moisture reaches the interior face of the wall. The vapour permeable lime render aids drying of the moisture to the external air, whilst internal lime plaster permits drying to the inside when conditions permit. Lime wash was also traditionally used as an important means of protecting walls from the wind and rain. It is important that the traditional external weathering of walls is maintained and repaired (e.g., brickwork repointed and render repaired, string courses, drips kept free of plant growth or other obstruction) to prevent long-term damage to the fabric. It is also important to use appropriate lime mortar to reduce heat loss through excessively damp building fabric. If the existing external envelope consists of cement render or other impermeable render, efforts should be made to restore the external envelope to its traditional permeable condition to enable the wall to dry out externally. Impermeable external coatings, including paints and cement washes, may limit the level of insulation that can be safely added to the internal surface.

This may not always be possible or recommended however, as there is increasing evidence of original cement-based renders being in use in Ireland on solid wall buildings from the mid-1800s onwards. These buildings will be particularly difficult to retrofit, especially where they are protected structures and usually require hygrothermal modelling by a qualified building physicist to achieve a satisfactory outcome.

Additionally, with increased rainfall as projected by the climate change models, there may be a need to increase the capacity of gutters and to install additional downpipes to discharge rainwater away from the building.

2.4.3 *PASSIVE HEATING*

The course of the sun is predictable for any given day of the year allowing for a full understanding of the impact of the sun on a building or site. In Ireland, about 40% of the sun's radiation is direct and 60% diffuse (scattered by cloud cover). Natural sunlight can be exploited to passively heat a building. The amount of sunlight available will be dependent on where the building is located and the level of cloud cover. Cloud cover can reduce the intensity of the sun, but the light can still be useful for the generation of energy (see Figure 22, which is further explored in Section 4.3).

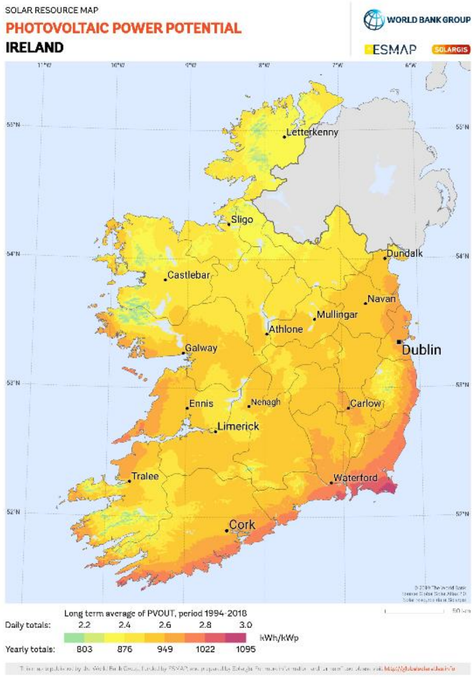

Figure 22 Irradiance Potential across Ireland[45]

The heating season is the period during which the external temperature drops significantly below comfortable internal temperatures, requiring some form of space heating within buildings. In Ireland, the heating season extends for a period of about 220 to 260 days, from mid-autumn through the winter and into late spring. During the heating season, heat within a building can come from a variety of sources. While stoves, central heating and open fires and a growing prevalence of heat pumps are currently the main sources of heat, a certain amount of heat is also gained from electrical appliances, televisions, computers, washing machines, lighting and indeed from the occupants of the building. Solar gain, the heat absorbed by a building from the sunshine which falls on it, can also have a positive impact on space heating requirements if properly used.

Many traditional buildings were constructed utilising site and sun, with, for example, smaller windows in the north facing elevations and larger windows in south facing. During daylight hours, buildings gain heat from the sun through windows. The amount of heat gained depends on the orientation, time of year, amount of direct sunlight or cloud cover, the type of glass in the windows and the nature of the materials within the building. When the sun is low in the sky, during the cooler seasons and early and late in the day, sunlight penetrates deeper into the interior of a building, providing a valuable source of heating energy (Figure 23). When sunlight falls on a solid internal surface, one with high thermal mass such as a wall or floor, it heats it. This heat later

[45] Global Solar Atlas 2.0, Solar resource data: Solargis. https://solargis.com/maps-and-gis-data/download/ireland

radiates back out of the wall or floor, providing a free source of extra warmth within the building. Large windows in many traditional buildings encourage the use of daylight, reducing the need for artificial lighting.

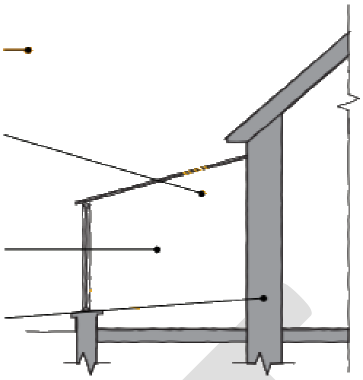

Figure 23 Solar gain: the 'greenhouse' effect. Traditionally, conservatories and greenhouses were built to maximise the advantages of the heat from the sun; sunlight entering through the glass warmed the air inside allowing for the cultivation of exotic flowers and fruits. The conservatory also provided a room for entertaining which was a place of transition between the house and garden.

As many retrofit projects encompass broader internal alterations to the property, designers consider ways to optimise the existing building form and glazing ratios for passive solar gain. In order to use solar gain to its full advantage, room uses and activities should correspond to periods of sunshine; generally, bedrooms and kitchens should face east to benefit from the morning sun and living rooms and dining rooms should face west for evening use

Appropriate seasonal use of space is also important. In general, the greater the area of exposed surface a building has, the greater the amount of heat loss that occurs so peripheral unused spaces (e.g. conservatories and sunrooms) can be left unheated or minimally heated to act as a thermal buffer. Likewise, buildings physically attached to one another are more efficient at retaining heat as the area of wall exposed to the elements is significantly reduced, notionally by about half in a terraced building and by about a quarter in a semi-detached one.

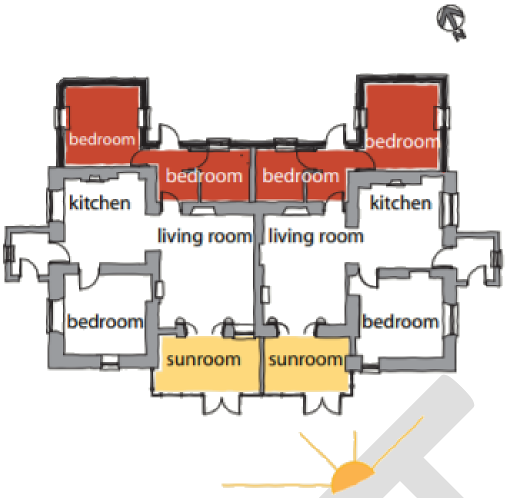

Figure 24 The floor plan of a pair of rural cottages shows, in red, a newly constructed, well-insulated, north facing extension housing bathrooms and bedrooms and, in yellow, south-facing sunrooms to take advantage of solar gain and provide heat and light to the living rooms behind.

The DEAP/NEAP methodology includes solar gain and heat loss calculations for all orientations and glazing types and has associated weather files to contribute to the calculations, so the BER of a building can be improved by reinstating or introducing passive heating mechanisms.

2.4.4 *PASSIVE COOLING*

Traditionally, the mechanical cooling of buildings has not been a requirement in Ireland's temperate climate. However, the projected changes in Ireland's climate means that warming during the summer will likely increase by 1 - 2.4°C[46], which may increase the need for cooling in some buildings during the summer months. Additionally, cooling sometimes becomes necessary in office environments, where the amount of heat generated by electronic equipment can be substantial and is usually emitted during the day when external temperatures are at their highest. The thermal mass of traditional solid walls tend to buffer the temperature changes, with natural ventilation providing enough of a cooling effect to maintain comfort levels. In this regard the traditional vertically sliding sash window offers a highly adjustable ventilation solution, with its top and bottom opening creating an optimum circulation of internal and external air.

[46] Regional climate models for Ireland can be found the EPA Research Report No. 159: http://www.epa.ie/pubs/reports/research/climate/research159ensembleofregionalclimatemodelprojectionsforireland.html

3 GENERAL GUIDANCE ON IMPROVING THE ENERGY EFFICIENCY OF TRADITIONAL BUILDINGS

Once an assessment of the existing building has been completed, the potential limitations and opportunities have been explored and energy efficiency targets have been set, one can then begin to consider the potential retrofit materials and measures required to meet these targets.

This section provides guidance on the standard energy retrofit material and measures that are typically suitable for traditional buildings. This is general guidance and as every building is different, the recommendations may not apply in all cases. It is up to the building professional to use their best judgement and to enlist specialist advice when required. It should be noted that many measures may require planning permission in the case of a protected structure so, in such cases, advice from a local authority conservation officer should be sought at the outset of the project. Upgrades to energy systems are discussed in Chapter 4.

3.1 DEVELOPING A RETROFIT STRATEGY

3.1.1 *PROCEDURE FOR DEVELOPING A RETROFIT STRATEGY*

A standard procedure for developing a retrofit strategy for traditional and historic buildings is set out in the *I.S. EN 16883: 2017: Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings.* The recommended procedure (summarised and adapted below) includes the steps necessary to identify the appropriate energy performance improvements for a particular building.

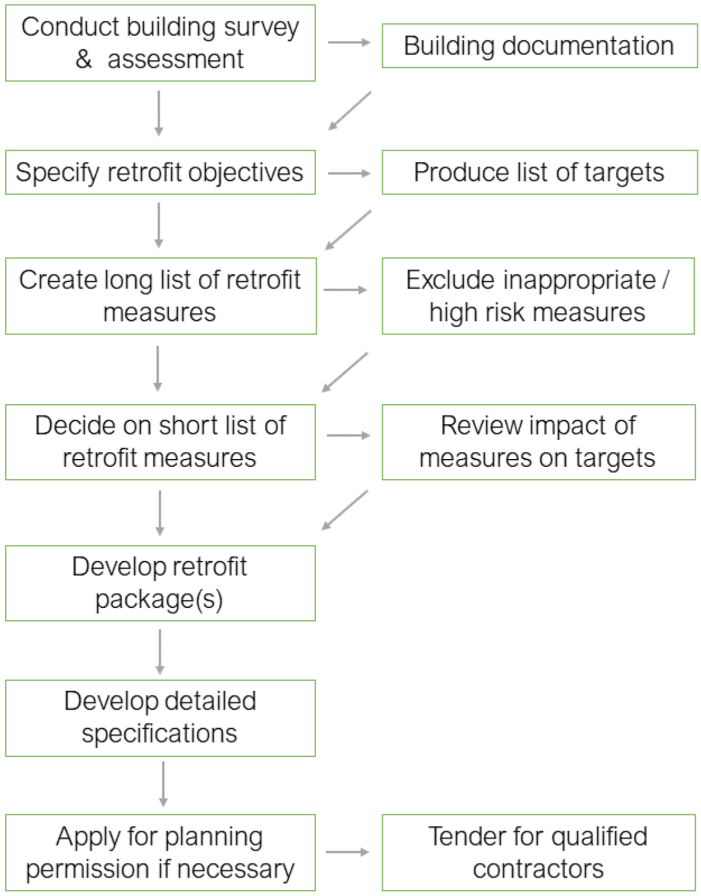

Figure 25 Standard procedure for developing a retrofit plan.

The process of assessing the improvements needed and setting the retrofit objectives (energy efficiency and decarbonisation targets) will determine the extent of retrofit measurements required and therefore whether planning permission that may be required. Even in non-protected traditional buildings, planning permission may be required for some works to the exterior of the building, such as the replacement of original sash windows or the addition of external wall insulation. This means that determining what interventions are required is an important early step to ascertain any statutory requirements of the project. Early consultation with the planning authority is advised.

A series of questions have been provided in Table 4 to help building professionals determine whether a building or proposed retrofit project is complex. Answering yes to any of these questions means the building or retrofit project should be considered complex and mitigation measures should be pursued to address the issue(s). Specialist advice and/or surveys may be required.

The general process for deciding whether to seek specialist advice and/or surveys is described in Figure 26.

Table 4 Checklist to determine if a building is considered complex.

	Question	Yes √	No √	Mitigation Measures
1	Is your building a Protected Structure?			
2	Is it in an Architectural Conservation Area?			
3	Is IWI going to be applied and are there any traditional or historic internal features (e.g. cornices, wainscotting, shutter boxes, timber floorboards, original plaster or decorative plasterwork, etc.)?			
4	Is EWI going to be applied and does the exterior of the building feature any decorative details that may be difficult or impossible to insulate over (e.g. dentils, window sills, decorative details, etc.)?			
5	Are there signs of moisture related problems such as dampness, staining or mould growth?			
6	Do the works require anything other than a standard solution, require significant repairs or are associated with either a Yellow or Red risk level in the traffic light system (Fig 7-10, Section 2.5.6)			

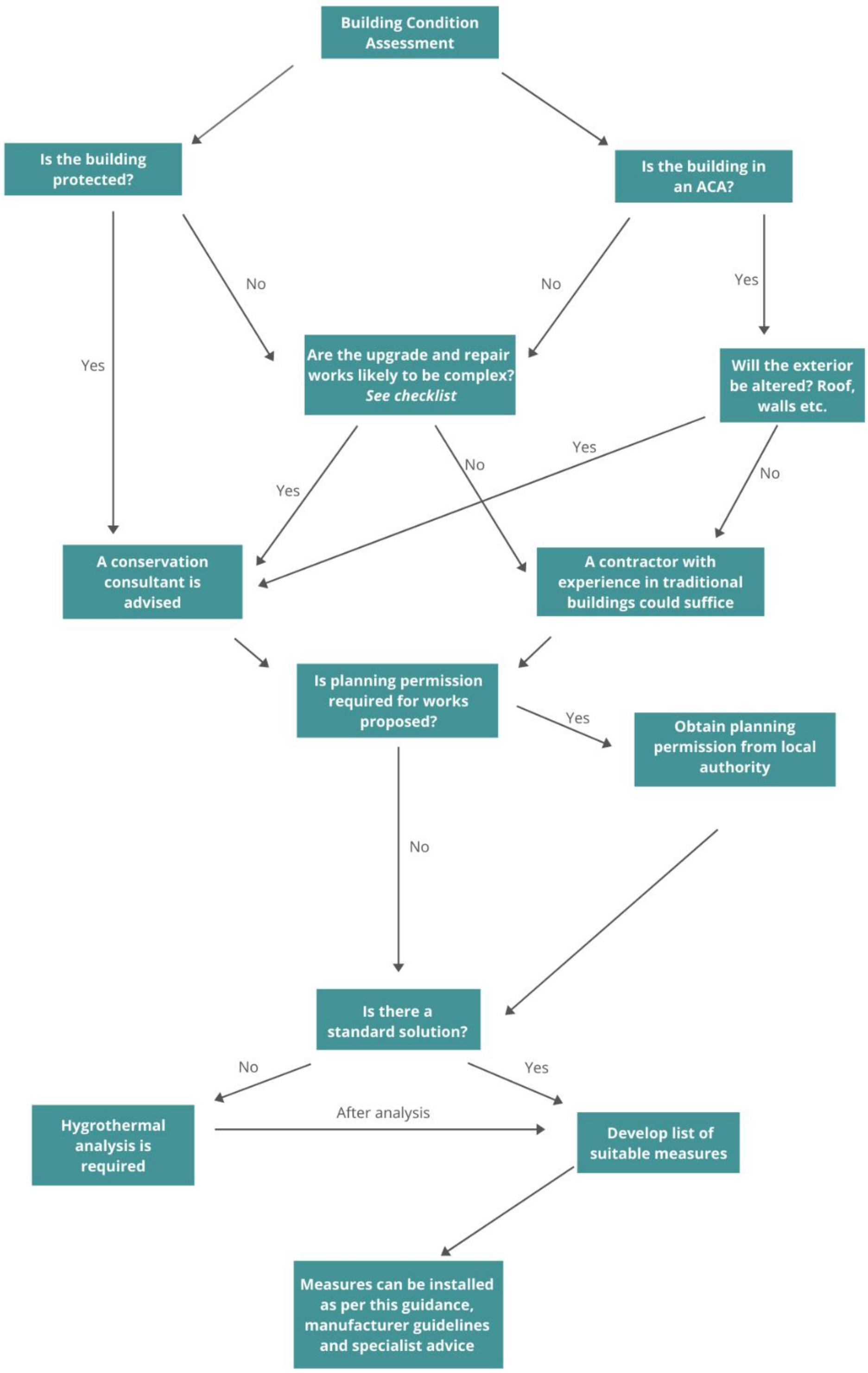

Figure 26 Standard procedures to determine when specialist advice and services are required.

3.1.2 *BUILDING CONDITION SURVEY*

Prior to embarking on any retrofit project, one must understand the building and in particular the condition of the building in question. A well-considered minor investigation to confirm and fully understand the construction details of the building is technically rewarding, provides an opportunity to deliver a cost-optimal renovation, reduces the impact of unnecessary interventions and results in a far better performing building in the long term. This knowledge and understanding also leads to a better energy survey/audit. **It is important before any energy upgrade works are installed that the repair works are carried out. For example, cement-based pointing, render/plaster will need to be removed where possible as they are not vapour permeable and vapour permeable insulation cannot be added on top of cement-based materials. It should be replaced with lime-based materials.**

It is important to identify any toxic materials such as lead pipes, asbestos, lead-based paints and contaminated plasters present in the fabric at an early stage and to plan for their containment or removal. Some common retrofit measures may restrict air movement and could increase the health risks associated with these materials. The presence of any such contaminants should be confirmed before any works take place to understand how the intervention may affect existing materials.

3.1.3 *ENERGY SURVEY/AUDIT*

Understanding the current energy usage of a building is essential in order to set realistic energy efficiency improvement targets. An energy survey or audit may range from a simple analysis of the energy bills to determine the annual and seasonal usage of electricity and fossil fuels to a full energy audit carried out by an SEAI registered Energy Auditor. It is important, however, to ensure that an energy auditor has an expert understanding of the specific requirements of traditional buildings as outlined in this document (table 3s) to ensure their advice is not in conflict with best practice for these buildings.

3.1.4 *HERITAGE CONSIDERATIONS*

Buildings or structures may be protected under the National Monument Acts (1930-2004). When dealing with older buildings, it is important to establish their legal status by checking if they are included in the Record of Monuments and Places (RMP)[47]. The RMP is a map dataset for each county that is maintained by the National Monuments Service of the Department of Housing, Local Government and Heritage and can be viewed on the website www.archaeology.ie or in a county library or main Local Authority office. Buildings subject to the National Monuments Acts are exempt from the requirements of the Building Regulations under Class 8, Third Schedule of the Building Regulations 1997 (S.I. 497 of 1997).

To comply with the legislation, a person intending to carry out works to a privately-owned building, structure or site that is included within the RMP must give two months' notice to the Director of the National Monuments Service of the Department of Housing, Local Government and Heritage before commencing works. Where a structure of national significance is in the ownership or guardianship of the State or a Local Authority, or is subject to a Preservation Order, Ministerial consent to carry out works must be obtained before works commence.

[47] Record of Monuments and Places, National Monuments Service: https://www.archaeology.ie/publications-forms-legislation/record-of-monuments-and-places.

In responding to the notice or application for consent, the National Monuments Service may grant or refuse permission to carry out the works, may request further information, or may require that an archaeological impact assessment, archaeological monitoring or archaeological excavation be carried out at the expense of the applicant. Where monitoring or excavation is a condition of the Ministerial consent, a licence eligible archaeologist must be engaged.

Anyone dealing with a traditional building or structure that is subject to these Acts should engage with their Local Authority archaeologist or the National Monuments Service for advice and guidance. They may also wish to consult a number of helpful publications such as the Framework and Principles for the Protection of Archaeological Heritage[48] and Archaeology in the Planning Process[49].

3.1.5 *Setting Energy Efficiency Objectives*

Standards for thermal comfort have increased greatly since the construction of many traditional buildings. The temperature at which an occupant is comfortable depends on several factors, such as air movement and humidity levels, and is different for everyone. It may not always be possible to bring traditional buildings up to modern thermal comfort levels and where this is the case, traditional methods of temperature control such as hanging tapestries on walls and installing shutters or heavy curtains on windows can increase thermal comfort without needing to increase space heating. Behavioural changes such as only heating the rooms in use or dressing warmer during cooler weather are sustainable actions that would also contribute to the more efficient operation of traditional buildings, pre- and post-retrofit.

With this in mind, along with the building's heritage status and the results of the condition assessment and energy survey/audit, expectations for the retrofit should be listed. Typical objectives may include but are not limited to:

- reduced operational emissions and/or fossil fuel consumption
- improved BER rating (e.g. B2)
- increased use of energy from renewable energy sources
- improved U-values of the building envelope (roof, floor, walls and/or windows)
- improved airtightness
- improved indoor air quality
- embodied carbon target (tonnes of CO2 e per m2 of a building)

To be able to accurately assess the success of the retrofit, these objectives must be based on actual data and should include the degree to which you aim to improve the building, e.g. improve the U-values of the walls from 2.1 w/m^{2}K to 0.75 w/m^{2}K. The objectives should also be realistic and based on past precedents.

3.1.6 *Selecting Options*

In all cases, there are graduated levels of interventions that can be pursued, starting with the "low hanging fruit". These low-risk upgrades will contribute to a reduction in energy use and operational emissions without

[48] Framework and Principles for the Protection of Archaeological Heritage: https://www.archaeology.ie/sites/default/files/media/publications/framework-and-principles-for-protection-of-archaeological-heritage.pdf.

[49] Office of the Planning Regulator (2021) Archaeology in the Planning Process. Available at: https://www.opr.ie/planning-leaflets/.

introducing a large amount of risk that would require specialist surveys and advice. Non-invasive measures may be the only ones appropriate for Protected Structures but that does not mean that energy and carbon emission savings cannot be made. **By this point, specialist advice and surveys should already have been commissioned if required to inform the selection of retrofit options** (see Section 3.1.1).

The specification of certain complex retrofit measures should be supported and informed by the results of analysis, including thermal and hygrothermal analysis, where these are required to confirm the long-term impact of the proposed measures on the building fabric. These analyses can ascertain the robustness of the existing building fabric and the suitability of the proposed retrofit measures. Insulation of the building should seek to ensure that the building can be heated in an economical manner, without prejudicing its character or causing long term damage to the fabric.

The maintenance of acceptable temperature and relative humidity levels is key to the performance and condition of the building fabric in the short- and long-term. As such, **any retrofit proposals must factor in the intended use of the building at the outset.** For instance, if a building that had been sparsely occupied is to be converted to a high occupation use such as student housing, this may rule out certain retrofit measures and require others that would not normally be required (e.g. mechanical ventilation).

It is important that any issues with moisture ingress are addressed first otherwise the addition of insulation is likely to exacerbate the problems.

More information about retrofit measures that are generally suitable for traditional buildings is provided in Chapter 3.

A series of common retrofit measures for roofs, walls floors and walls have been provided in Table 6 - **Error! Reference source not found.** with the associated level of risk they pose to the longevity of the building fabric in terms of thermal bridging, condensation and ventilation. The risk level ranges from low (green) to high (red) (Table 5), but ultimately it is up to the building professional to decide when expert advice or additional surveys are required to confirm that the proposed retrofit measures would not harm the building fabric or occupants.

Table 5 The risk levels associated with potential impact of retrofit measures on the longevity of the building fabric.

Colour	Risk Level
Green	Little-to-no likelihood of long-term risk to building fabric, minimal intervention required
Yellow	Some long-term risk to building fabric likely, suitability will depend on the building
Red	High likelihood of long-term risk to building fabric, expert advice required

In Protected Structures/ACAs, risk should be classed as Red across all categories. Conservation consultants should be consulted at the outset of the project.

These tables are designed to act as a general guide to the associated risk levels of common retrofit works for traditional buildings, but as the context, condition and construction of each building can differ it is recommended that building professionals carry out their own risk assessment at the outset of a retrofit project.

Note: These tables are under development and further information will be provided in the final draft.

Table 6 Upgrade options for roofs and their associated risks.

		Associated Risk					
	Retrofit Measures	**Historic Significance**	**Thermal Bridging**	**Condensation**	**Ventilation**	**Mitigation Measures**	**Specialist Required**
Pitched Roof	**Insulating at ceiling level (cold roof)**	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		
	Insulating below ceiling level	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		
	Insulating at rafter level (warm roof)	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		
Flat or low pitched roofs	**Insulating at ceiling level (cold roof)**	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		
	Insulating below the ceiling	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		

Table 7 Upgrade options for walls and their associated risks.

		Associated Risk					
	Retrofit Measures	**Historic Significance**	**Thermal Bridging**	**Condensation**	**Ventilation**	**Mitigation measures**	**Specialist Required**
Walls	**Repairing (including repointing and repairs to existing vapour permeable lime renders & plasters)**	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		
	Applying new vapour permeable lime renders/plasters	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		
	Internal Wall Insulation (IWI)	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		
	External Wall Insulation (EWI)	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		

Table 8 Upgrade options for windows and doors and their associated risks

	Retrofit measures	Historic Significance	Thermal Bridging	Condensation	Ventilation	Mitigation Measures	Specialist Required
		Associated Risk					
Windows & Doors	Draughtproofing	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		
	Refurbishing or replacing lost shutters	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		
	Adding secondary glazing	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		
	Insulating window/door reveals	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		
	Replacing windows/doors	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		

Table 9 Upgrade options for floors and their associated risks

		Associated Risk					
	Retrofit measures	**Historic Significance**	**Thermal Bridging**	**Condensation**	**Ventilation**	**Mitigation Measures**	**Specialist Required**
Floors	**Insulating existing solid ground floors**	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		
	Draught-sealing suspended timber floors	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		
	Insulating suspended timber floors (insulating from above or below)	Green option	Green option	Green option	Green option		
		Yellow Option	Yellow Option	Yellow Option	Yellow Option		
		Red Option	Red Option	Red Option	Red Option		

3.1.7 *PREPARING FOR POST-RETROFIT OCCUPATION*

The anticipated usage patterns are built into the DEAP/NEAP calculation for each intended use of the building. Where a building is being used or returned to use as a dwelling, a number of factors will determine the anticipated conditions in the building such as number of occupants, hours/duration of occupancy, lifestyle of occupants, knowledge of proper building management and maintenance. These are all standardised in the DEAP/NEAP calculation to allow buildings with similar uses to be compared with each other.

Where, for example, a building is being used for commercial office purposes, occupancy patterns may be relatively predictable, as are perhaps moisture load, internal heat gains, as well as anticipated production of harmful gases or elements previously discussed under IAQ. In the context of building fabric retrofit measures, maintaining temperature levels and relative humidity levels within an acceptable range is key to performance of retrofit measures and the condition of the building fabric in the short and long term. As such, **any retrofit proposals must immediately factor in the intended use of the building.**

It is recommended that occupants be given a guidance booklet providing a high-level understanding of the parameters which affect building performance, comfort, energy consumption, overheating control, and general building management requirements. A possible list of information to include in such a guide is presented in Table 10. This list is adapted from the Irish Green Building Council's Home Performance Index Technical Manual[50].

Table 10 Information that can be included in a handover guide to building occupants

Item	Information to be included in guide
Ventilation	Introduction to importance of ventilation for indoor air quality and moisture control
	Description of installed ventilation system
	How the system works and operation details - location of control indicators should
	Maintenance requirements – Filters etc. where relevant and where to get them
	Contact details if problem arises with system and links to manufacturers manuals
Heating/Cooling System	Introduction and expected costs based on standard usage
	Description of installed system
	How the system works and operation details
	How to programme and maintain maximum efficiency throughout the year
	Maintenance requirements
	Contact details if problem arises with system and links to manufacturers manuals
Renewable Energy Systems	Description of installed system
	How the system works and operation details
	Maintenance requirements
	Contact details if problem arises with system and links to manufacturers manuals
Lighting Systems	Description of installed system
	How the system works and operation details
	Maintenance requirements
	Contact details if problem arises with system and links to manufacturers manuals
General Maintenance	General maintenance requirements and frequency of replacement for windows, gutters, downpipes, drainage etc

[50] The Home Performance Index, http://homeperformanceindex.ie/wp-content/uploads/2020/09/HPI-technical-Manual-v2.0_with_corrections_since_publication.pdf

3.2 MATERIALS

Traditional buildings are built with solid walls of vapour permeable materials, such as brick, stone, timber, lime mortar, lime renders or plasters, which have different levels of vapour permeability. As explained in Section 2.1, it is essential that retrofit materials and measures are compatible with the existing structure in order to permit the natural movement of moisture.

In addition to reducing energy use and operational emissions, retrofit works should also aim to reduce embodied emissions by taking a whole life carbon approach to the selection of materials and products. This should consider the Global Warming Potential (GWP) for manufacture, their performance in use, their service life, as well as their potential for reuse, recycling and disposal at end of life.

Aesthetics and heritage impacts are also of importance with traditional buildings and careful consideration should be paid to these two factors. Retrofit materials or measures that are not compatible with the existing fabric or which alter the unique features of the building are not recommended.

Any materials used should comply with TGD Part D[51] and Part L[52]. TGD Part D defines proper materials as materials which are fit for the use for which they are intended and for the conditions in which they are to be used, and includes materials which:

(a) bear a CE Marking in accordance with the provisions of the Construction Products Regulations;

(b) comply with an appropriate harmonized standard, European technical approval or national technical specification as defined in article 4(2) of the Construction Products Regulations;

or

(c) comply with an appropriate Irish Standard or Irish Agrément Board Certificate or with an alternative national technical specification of any State which is a contracting party to the Agreement on the European Economic Area, which provides in use an equivalent level of safety and suitability.

TGD Part D acknowledges that the guidance within it may not apply to existing buildings without modification, particularly in relation to adherence to codes, standards and technical details as these were designed for application in new buildings. **In this case, TGD D leaves open the possibility to pursue alternative approaches that comply with the Constructions Products Regulations.** While the primary route for establishing the fitness of a material for its intended use is through the recognised standardisation procedures as referred in the paragraphs above, other methods may also be considered in establishing fitness, including:

i. Approval by independent certification schemes by approved bodies, e.g. the National Standards Authority of Ireland (NSAI).

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[51] Department of Housing Local Government and Heritage (2019) Technical Guidance Document D: Materials and Workmanship, Dublin: Department of the Environment, Community and Local Government. Available at: https://www.gov.ie/en/publication/87e51-technical-guidance-document-d-materials-and-workmanship/.

[52] Department of Housing Local Government and Heritage (2019) Technical Guidance Document L: Conservation of Fuel and Energy - Buildings other than Dwellings, Dublin: Department of the Housing, Planning and Local Government. Available at: https://www.gov.ie/en/publication/80125-technical-guidance-document-l-conservation-of-fuel-and-energy-buildings-other-than-dwellings/.

ii. Tests and calculations carried out by an accredited laboratory or assessor showing that the material is capable of performing the function for which it is intended. Accreditation by a member of the European cooperation for Accreditation (EA) such as the Irish National Accreditation Board (INAB) offers a way of ensuring that tests are conducted in accordance with recognised criteria and can be relied on.

iii. Performance in use, i.e. that the material can be shown by experience, such as its use in a substantially similar way in an existing building with a similar external climatic environment (rainfall, wind, temperature, relative humidity, etc) and with similar internal risk profiles (occupancy, relative humidity, temperature, ventilation, etc) to be capable of enabling the building to satisfy the relevant functional requirements of the Building Regulations.

Where such alternative methods are used to demonstrate compliance to the satisfaction of the Local Authority Building Control Officer, the specifier of the product must ensure that materials are fit for the use for which they are intended and for the conditions in which they are to be used. **In assessing the fitness for use and conditions of use of a material/ product, consideration should be given to durability, safety, local climatic conditions** (e.g. wind driven rain, humidity etc.) and other such issues.

Further general information and guidance on insulations, renders/plasters, pointing and finishing coatings are provided in the sections immediately below and more detailed recommendations on their application can be found in the following sections related to the upgrade of each building element (see Section 3.3 - 3.7).

3.2.1 *INSULATIONS*

While thermal conductivity is often the only factor considered when specifying an insulation type for the thermal upgrade of a building, other factors such as the vapour diffusion resistance factor, embodied energy, global warming potential, toxicity and biodegradability should also be taken into consideration.

Modern petrochemical-based insulations usually have higher associated embodied emissions than both mineral and bio-based insulations. EPS and PUR/PIR have a high vapour diffusion resistance factor, meaning they inhibit moisture from moving through them and will instead force the moisture to move through porous traditional materials, which will expediate their decay.

Mineral based insulations are produced from naturally occurring minerals and are therefore easier to safely dispose of than petrochemical based insulations. Mineral based insulations tend to have higher associated embodied emissions than bio-based insulations due to the intense processing required to convert the minerals into insulation materials. They are vapour permeable however, which makes them suitable for use in traditional buildings. Calcium silicate boards (mixture of lime and sand) are capillary active, hygroscopic and have anti-mould properties, making them suitable for high humidity environments. They also provide high levels of insulation (0.059 W/mK) with relatively little thickness (30-50mm).

Bio-based insulation materials are usually vapour permeable and tend to have the lowest associated end-of-life emissions as they are naturally occurring, require little processing and are easiest to dispose of safely. Cork or hemp can be mixed with traditional lime renders and plasters to produce an insulating yet vapour permeable natural lime finish that is both visually and technically appropriate for traditional buildings.

In TGD Part L, the acceptable levels of thermal insulation for each of the plane elements of a building are specified in terms of average area-weighted U-value (Um) for material alterations and material changes of use

(Table 11). These values can be relaxed for individual elements or parts of elements where considered necessary for design or construction reasons.

Table 11 Maximum elemental U-value (W/m²K) for Material Alterations or Material Change of Use.

	Fabric Elements	**Area-weighted Average Elemental U-value (Um)**	**Average Elemental U-value – individual element or section of element**
Roof	**Insulation at ceiling**	0.16	0.35
	Insulation at rafter	0.25	
	Flat Roof	0.25	
Wall	**Cavity**	0.55	0.6
	Other	0.35	
Floor	**Ground Floor**[a]	0.45	0.6
	Other exposed Floor	0.25	
	External doors, windows, rooflights and curtain walling	1.4[b], 1.6[c]	3

Notes

a	*Only applies where floors are being replaced*
b	*For dwellings*
c	*For other than dwellings*

General application guidelines for a number of hygroscopic insulations suitable for use in traditional buildings are provided in Table . All insulation should be installed according to manufacturer guidelines.

Table 12 Common hygroscopic insulation materials suitable for traditional buildings and their typical characteristics. *Note: specific products from manufacturers may differ slightly.*

	Structure	Typical Thickness (mm)	Thermal Conductivity W/mK	Typical Use	Notes
Woodfibre	Soft to Rigid	20 - 100	0.039	Internal even dry wall	Requires completely dry wall, moisture ingress issues must be fixed first. Very good sound insulator. High reuse and recycle capacity
Hemp	Soft	40 - 160	0.04	Roofs, walls, ceilings and floors between rafters, joists and studs. Can also be used in lofts between and over ceiling joists.	Tear-resistent, insect and rodent resistent. High reuse and recycle capacity
Cork	Rigid	40 - 240	0.043	Exterior wall cladding, interior walls and ceilings	Good acoustic insulation. High reuse and recycle capacity
Flax	Soft	30 - 150	0.038	Roofs, walls, ceilings and floors	Easy application. Lightweight
Sheep's Wool	Soft	50 - 300	0.042	Roof, ceiling, ground floors	No protective equipment required for installation, good sound insulator. High reuse and recycle capacity
Mineral: Rock Wool	Soft to Semi-Rigid	40 - 100	0.032-0.044	Pitched and flat roofs, underneath wooden floors, in interior walls	High elasticity, high density. Fibres can irriate nasal passages and eyes, proper protective equipment should be used.
Mineral: Glass Wool	Soft to Semi - Rigid	40 - 100	0.035-0.039	Pitched and flat roofs, underneath wooden floors, in interior walls	Low elasticity, low density, high fire resistence. Fibres can irriate nasal passages and eyes, proper protective equipment should be used.
Mineral: Slag Wool	Soft to Semi - Rigid	40 - 100	0.03 - 0.04	Pitched and flat roofs, underneath wooden floors, in interior walls	Slag is a byproduct from steel production
Calcium silicate boards	Rigid	30 - 50	0.059	Interior side of external solid stone or masonry walls, solid concrete walls or ceilings	Capillary active, thin insulation (ideal for internal insulation). Non-combustible
Silica Aerogel	Rigid	10 - 15	0.018	Roof and floor insulation where space is an issue	Very light weight, ideal for roofs
Cork-lime insulating plaster	Spray on	15 - 60	0.045	For uneven internal or external walls	Capillary active, high elasticity, easy thermal bridge solution. Application with spray results in less material waste compared to Application with trowel

3.2.2 *RENDERS/PLASTERS:*

If a traditional building has a lime based external render or internal plaster the material used should be lime-based as this maintains freedom of moisture movement within the vapour permeable envelop. In many cases this lime-based product may have been replaced in recent times with an inappropriate cementitious based material which is not vapour permeable and which has the potential to trap water within the building fabric. **In general, a cementitious based material (which can be identified as being harder than lime render) on a traditional building should be removed if it is possible to do this without damaging the building fabric** whether it is in the form of a render, an internal plaster or cement-based mortar for pointing of stone or brick.

Insulating lime renders and plasters are most suitable for traditional buildings, they are vapour-permeable and can improve the thermal efficiency of all solid wall construction and can be used successfully on external and internal applications subject to confirmation via hygrothermal analysis.

Figure 27 Example of cement render applied to a traditional building. Water from a leaking drainpipe can penetrate the cement render and increase moisture build up in the wall. This can lead to rot in any timber elements in contact with the wet masonry.

Figure 28 Same building with the drainpipe leak fixed and the cement render replaced with a traditional moisture permeable lime render.

3.2.3 *POINTING*

In the case of an exposed external brick or stone finish, the lime-based pointing materials should be used. The function of joint is to allow moisture freedom of movement within a vapour permeable envelope. When this is changed to a cement-based system it forces the moisture through the stone or brick which results in physical damage to that material. The pointing should always be softer and therefore sacrificial to the brick or stone. **Cement-based pointing also retains or traps moisture, which can result in a damp wall that is cold and less energy efficient.**

3.2.4 *PAINTS*

Vapour permeable paints are advised such as lime or clay-based paints. Standard vapour-closed paints will restrict the natural movement of moisture even if vapour open insulations and materials have been used.

3.3 ROOFS

Insulating an attic or roof is generally one of the most effective and non-intrusive measure to improve the energy efficiency of a traditional building. An estimated 25% of heat is typically lost through a building's roof. The roof is exposed to the outside elements, and where problems exist with the roof, these effects can extend throughout the rest of the building. This means that starting with improving the roof and adding insulation is a good step to improve the energy performance of the entire building. Two options are available for roof improvements: ceiling insulation and rafter insulation.

Ventilation is a very important for roofs. With poor ventilation, moisture can enter the roof from the rest of the building and if the roof is unventilated, interstitial condensation can occur, increasing the risk of mould growth.

Prior to embarking on insulation works, decisions will need to be made based on the existing condition and build-up of the roof, ventilation provisions and restrictions, and how the attic space it is intended to be used. This will determine which insulation method should be pursued.

The diagram below demonstrates the minimum ventilation void required in different roof build-ups to maintain a healthy internal environment and to avoid condensation.

Diagram 11: Ventilating roof voids

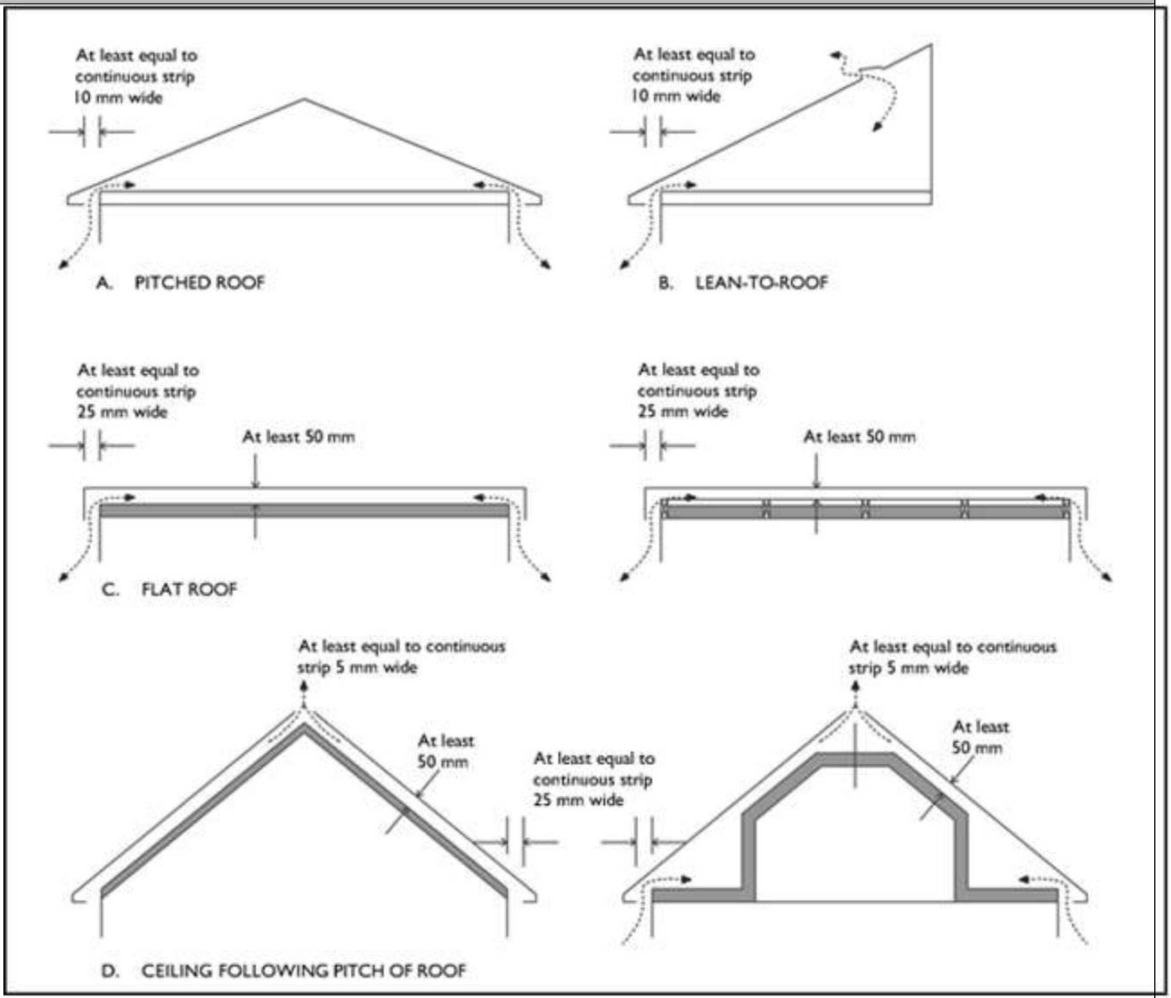

Figure 29 Diagram 11 from TGD Part F[53] - Ventilating roof voids – minimum ventilation gaps recommended to allow sufficient air movement over the insulation to remove excess moisture.

3.3.1 *CEILING INSULATION (COLD ROOF)*

Preparation

Lofts will need to be cleared of any stored items as well as any redundant cables or plumbing. Anything that is not important structurally may need to be removed so that insulation can be applied uniformly. Any cabling that must remain should be raised above insulation where possible or be run in conduit to prevent overheating beneath the insulation. Where recessed light fittings are present in the ceiling below the roof, existing insulation may have been removed to reduce the risk of overheating. New or additional insulation will have to work around these light fittings, which could cause some gaps. Insulated hoods are available to overcome the problem. The

[53] Department of Housing Local Government and Heritage (2019) Technical Guidance Document F: Ventilation, Dublin: Department of the Environment, Heritage and Local Government. Available at: https://www.gov.ie/en/publication/62f06-technical-guidance-document-f-ventilation/.

replacement of existing light fitting with LED light fittings can achieve significantly lower temperatures and use significantly less energy, reduce moisture transport into unheated voids/spaces and therefore reduce moisture risks as well as help to improve the energy efficiency of the building and should always be considered first in a low-energy building strategy.

It is very important that any sources of water ingress in the roof space be identified and mitigated and all other necessary repairs be made before insulation is added.

It may also be important to check for any wildlife, such as bats, that can be found in unused lofts. When considering any works to a historic roof, if there is evidence or suspicion of bat presence the first step is to have a bat survey carried out by an appropriately qualified bat expert. Where bats are present or there is evidence that they have used, or are using a roof space, the National Parks and Wildlife Service should be contacted for advice[54] and guidance before any roofing works are programmed and initiated. Additionally the Bat Mitigation Guidelines for Ireland should be consulted[55]. Guidance on other types of wildlife that can be found in older building can be found in the BirdWatch Ireland report *Wildlife in Buildings: Linking our built and natural heritage*[56].

Materials

Insulation materials such as woodfibre, calcium silicate, flax, sheepswool, mineral wool, hemp wool and cork are moisture permeable insulations. They are 'hygroscopic' which means they allow the safe movement, storage and dissipations of moisture. The advantage of this is that it can reduce moisture build up inside a building, which protects adjacent structural elements such as timber from excess moisture.

Installation

Any existing insulation should first be assessed to determine if it needs to be re-laid or replaced. Ensuring that there are no gaps, the first layer of insulation should be laid between and to the full depth of the joists, right up to adjacent walls where possible. It will be important to achieve a continuous line of insulation at eaves, extending the insulation as far as possible over the wall-plate and leaving a minimum continuous eaves gap of 25mm over the insulation for air flow**.** Air flow in an insulated roof is extremely important, as moisture can build up in the roof, and without adequate ventilation, can lead to damage and decay of roof timber.

To cover any thermal bridges, the second layer of should be laid perpendicularly across the joists. Care must be taken to fit the insulation neatly around any trusses which are in the way to avoid any gaps.

A walkway may need to be installed over the insulation if the loft is to be used for water tanks, storage or if frequent access to it is required. Care must be taken to avoid compression of the insulation when installing the walkway. Insulated walkway panels which do not generate interstitial condensation are preferable. Alternatively, diffusion-open boards may allow any trapped moisture to escape.

In buildings where a section of the ceilings are sloped in line with the roof pitch (sometimes referred to as a 'coombe'), a hybrid approach using both ceiling level and rafter level insulation will be required. As there will not likely be space to add an insulating sarking board to the external face of the rafters, it may be possible to

[54] National Parks and Wildlife Services contact details can be found at https://www.npws.ie/contact-us
[55] Bat Mitigation Guidelines for Ireland: https://www.npws.ie/sites/default/files/publications/pdf/IWM25.pdf
[56] Sullivan, I. and Lusby, J. (2021) Wildlife in Buildings: Linking our built and natural heritage: BirdWatch Ireland. Available at: http://docstore.kerrycoco.ie/KCCWebsite/heritage/wildlifebuildings.pdf.

add a moisture permeable insulating board (such as woodfibre board) to the internal face of the rafters to increase the level of insulation on the coombe. Insulating roofs with a coombe presents more risks so it is recommended to undertake hygrothermal risk analysis and thermal bridge risk assessments to ensure that the proposed insulation materials and installation methods will not lead to any unintended consequences.

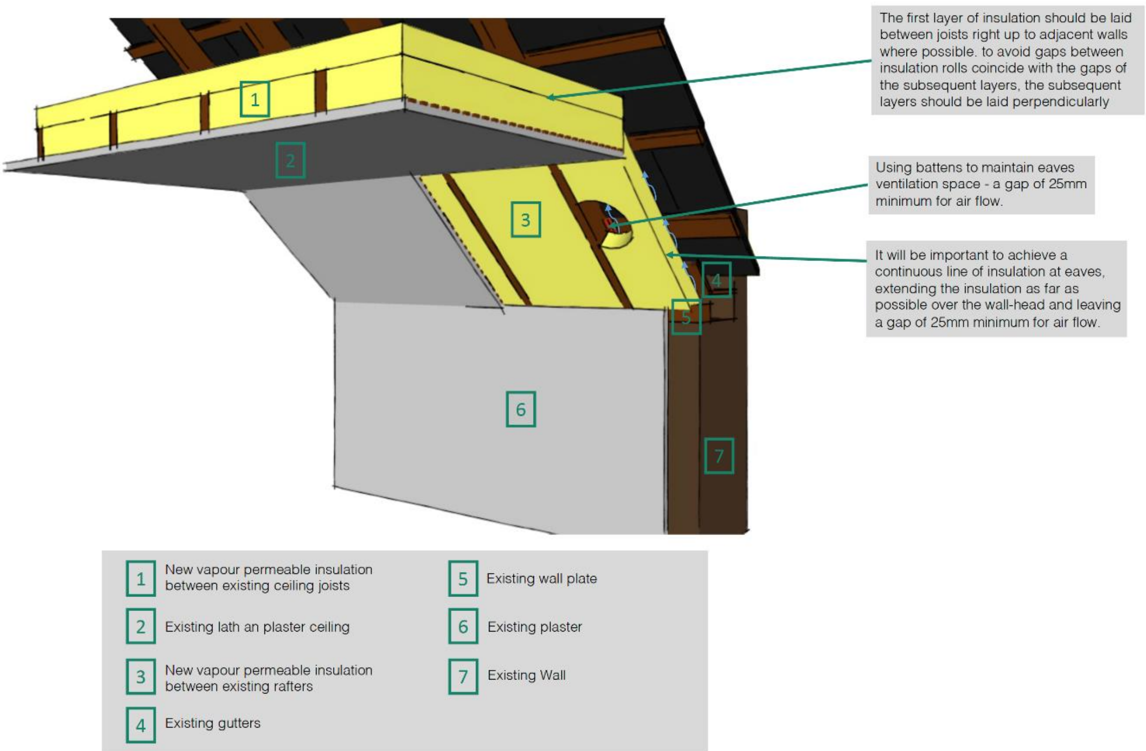

Figure 30 Recommended build-up of insulation and materials at ceiling level where a coombe exists.

Once the ceiling is insulated properly, during the winter the loft may become quite cold therefore any live pipework, water tanks or ductwork will need to be fully insulated/lagged (Figure 31). Note that the area below the water tank should be left uninsulated to allow heat from the room below to warm the water tank during the winter. Vapour-tight insulation is recommended to prevent the moisture in the warm air condensing on the cold pipework. Alternatively, these services may be relocated within the heated building, if possible.

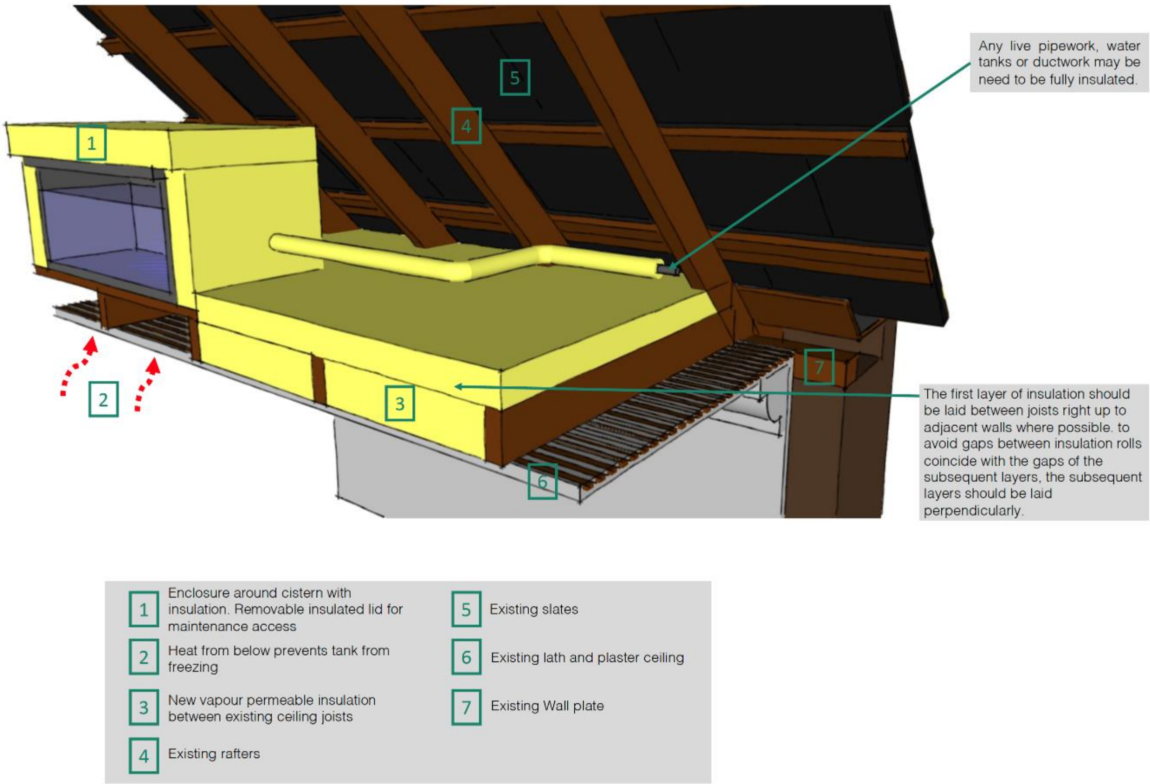

Figure 31 Typical ceiling and water tank insulation measures.

Where possible, ceiling hatches should be insulated to the same level as the rest of the loft, though this may be difficult to achieve. It may suffice to use rigid board insulation on simple hatches, working around any features such as ladders. Vapour control membranes should be sealed around the perimeter of the hatch with airtightness tapes; compressible draught-proof stripping must be installed at the perimeter of the attic hatch.

In addition to ensuring adequate ventilation, measures should be taken to limit transfer of water vapour to the cold attic. Care should be taken to seal around all penetrations of pipes, ducts, wiring, etc. through the ceiling, including provision of an effective seal to the attic access hatch. Use of a vapour control membrane on the warm side of the insulation at ceiling level can assist in limiting vapour transfer but cannot be relied on as an alternative to ventilation. Where the roof pitch is less than 15deg, or where the shape of the roof is such that there is difficulty in ensuring adequate ventilation, e.g., dormers or bay windows, an effective vapour control membrane on the warm side of the insulation is essential.

Figure 32 Vapour control membrane fitted to the warm side of the insulation to reduce vapour transfer from the room below.

3.3.2 *Rafter Insulation (Warm Roof)*

Alternatively, the roof can be insulated at rafter level in line with the pitch of the roof. This is known as 'warm roof' insulation as it creates a useable attic space.

Preparation

Access to the rafters will need to be gained either externally or internally. If internal finishes are historically valuable, existing slates/tiles will need to be carefully removed and should be stacked for re-use. At this time, the condition of the rafter ends and wallplate should be inspected. If the internal plaster is due to be removed or is not present, then access to the rafters can be gained internally. Necessary repairs to the rafter ends and wallplate should be made prior to the installation of insulation. Where both internal and external finishes are historically significant, it may still be possible to insulate at rafter level by cutting away a 600mm wide horizontal strip mid-way up the internal plaster to allow access and to ensure insulation is installed neatly to the eaves and fills the space available, maintaining the 50mm ventilated cavity above the insulation. Advice should be sought from the local Conservation Officer beforehand if the building is a Protected Structure.

Materials

Moisture permeable materials must be used for rafter insulation, e.g., woodfibre, hemp fibre, mineral wool, etc., to reduce the risk of moisture build up and timber decay. If space is limited, insulation products with aerogel can improve thermal performance significantly with a minimal thickness. These products must also be moisture permeable and foil-backed insulations are not recommended as they can lead to moisture accumulation in the timber rafters, which will expediate their decay.

Installation

Insulating at rafter level works best when the external roofing materials (slates, tiles, etc) are due for replacement. This then allows for the placement of insulating sarking boards (e.g., woodfibre) above the rafters, followed by a vapour permeable wind-tight membrane over the external face of the rafters, thus reducing the risk of thermal bridging through the rafters (Figure 33). A system of battens and counter-battens will need to be installed to the outer face of the rafters will provide the necessary structure to affix the slates/tiles to and will provide adequate space for ventilation between the windtight membrane and tiles.

Where dormer windows exist, the dormer cheeks and roof need to be insulated to a similar level as the rest of the roof to avoid heat loss through these areas. The cheeks, which are often the narrowest part of a dormer, can be challenging to upgrade as it is often very difficult to install a sufficient thickness of insulation whilst also creating the ventilation paths which are required. If the roofing is being replaced, it could be feasible to remove the roof and cheek claddings from the dormer(s) in order to install insulation from the outside, complete with insulating sarking boards, airtight membranes and a batten and counter batten system. If external roofing and cladding cannot be removed, a decision will need to be made on a case-by-case basis on whether it is acceptable to remove internal finishes bearing in mind the architectural character of the building[57].

[57] For more detailed analysis of dormer insulation, see Pickles, D. (2016) Energy Efficiency and Historic Buildings: Insulating Dormer Windows: Historic England. Available at: https://historicengland.org.uk/images-books/publications/eehb-insulating-dormer-windows/.

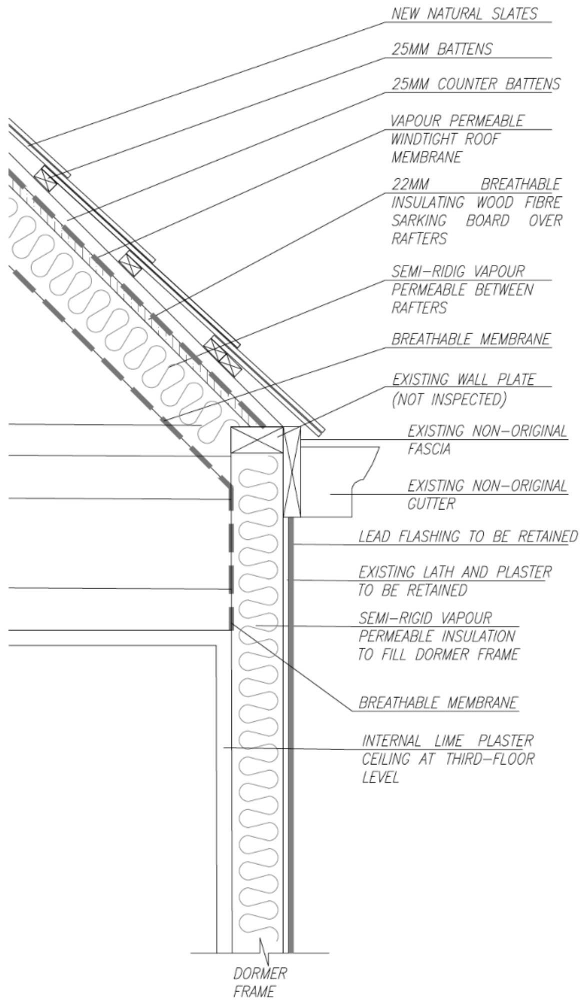

Figure 33 Proposed method to insulate the roof and dormers if the existing roofing materials are due to be replaced.

Where the roof levels need to be maintained (e.g. terrace buildings) or where access can only be gained from the inside, thermal bridge modelling should be done to ensure that the omission of the sarking board to the external face of the rafters would not cause issues. If the rafters are open internally or the existing plaster is to be removed, insulation can be added to the depth of the rafters with a breathable vapour control airtight membrane laid between the insulation and new ceiling finishes (see TGD Part L, Diagram B4). As with ceiling level insulation, softer insulation should be compressed to fit snugly between the rafters and should fill the full depth of the rafters. Where necessary, insulating tapes can be used to seal any gaps between the insulation and rafters. Woodfibre insulation boards can also be installed to the internal face of the rafters to increase insulation levels and improve airtightness.

Figure 34 Woodfibre insulation boards fixed over roof insulation and cut around attic hatch. The attic hatch must also be insulated as far as possible to minimise thermal gaps.

Figure 35 Woodfibre insulation board fixed to directly to the internal face of rafters of the coombe. This would only normally be done if a woodfibre sarking boards cannot be installed to the external face of the rafters.

In roofs with original lath and plaster finish on at rafter level, it may be preferred to keep the finish as intact as possible. In this situation, rigid boards or soft roll type insulation could be carefully pushed in behind the lath and plaster using a long and thin instrument. It will however be difficult to know if all gaps have been filled and the local authority conservation officer should be consulted on the potential to remove a horizontal band of lath and plaster midway down the ceiling to ensure that the insulation fully fills the voids.

It is important to maintain adequate ventilation levels to allow for the removal of excess moisture. The insulation should extend as far as possible over the wall plate, leaving a 25mm minimum gap at the eaves and a minimum 50mm gap to the cold side of the insulation for air movement. TGD Part F[53] Diagram 11 demonstrates the minimum ventilation gaps required for different roof build-ups (Figure 29).

As with ceiling level insulation, care must be taken with any electrical cables – they should be relocated if possible or placed within conduit to avoid overheating when under insulation.

Compliance with TGD Part F must be achieved as far as is reasonably practicable with any roof insulation upgrade. Any roof design should be checked in accordance with IS EN ISO 13788 and/or IS EN ISO 15026 as appropriate to ensure no risk of interstitial condensation exists.

3.3.3 *CHIMNEYS*

Chimneys are an important part of the ventilation system of a traditional building. The rising air in the chimney draws new air into the room from under the floor and behind plastered surfaces, keeping void spaces and hidden areas dry. If chimneys are closed off permanently, the ventilation requirements of the building will have to be met by other ventilation provision as described in TGD F. Instead of closing off chimneys permanently, **chimney balloons can be used to reduce draughts while also allowing for the occasional use of the chimney.** Chimney caps tend to be more useful for preventing birds nesting or debris falling into the chimney rather than for draught proofing.

Where chimney flues are being considered for ventilation, the flue and chimney should be checked and if necessary, altered to ensure that they satisfy the requirements for ventilation. Relining or repairing existing lining may be necessary, this should be done in accordance with TGD Part J – *Heat Producing Appliances*. Where a fireplace is being retained as an open fire space, adequate permanent ventilation must be provided to the flue (i.e. 550mm^2 per kW of rate output and no less than 6500mm^2 where air permeability is less than 5.0m^3/(h.m^2)). Using existing chimneys for open fireplaces is further discussed in Section 4.1.2.

Chimneys can be insulated to reduce heat loss through the fabric of the chimney. The thermal bridging resulting from a heavy mass of wet, cold masonry penetrating an insulation layer is significant and usually results in a failure to achieve the minimum surface temperature required to avoid surface condensation and mould growth. It is difficult to advise on how to insulate a chimney and three-dimensional thermal modelling may be required to establish a fully compliant solution. Before any insulation is added however, any necessary repair works on the chimney should be carried out, ensuring pointing, cappings and flashings are in a state of good repair and the flues are fitted with rain-shedding cowls or terminals. When carrying out work on a chimney, ensure that any replacement work matches the original, in colour, texture and compressive strength. If the coping is being replaced it should be done in appropriate materials, with the correct drip detailing on the underside to ensure water is shed clear. Many traditional buildings have a string course or band of projecting masonry that throws water clear of the gable. With suitable airflow controls, chimneys can continue to be used as ventilation shafts within designed ventilation systems. Where a chimney is to remain to be considered a part of the natural ventilation strategy for the building, the existing chimney liner must be thoroughly inspected and cleaned.

According to TGD Part J, chimneys and flue liners should provide satisfactory control of water condensation:

(a) for chimneys connected to non-condensing appliances the flue liner should be insulated so that flue gases do not condense in normal operation;

(b) for chimneys connected to condensing appliances

(i) lining components should be used that are impervious to condensate, have suitable resistance to corrosion (I.S. EN 1443 “W” designation) and have appropriate provision for draining, avoiding ledges, crevices, etc. and

(ii) provisions should be made for the disposal of condensate from condensing appliances.

It is not recommended that chimneys be removed. Efforts should always be made to restore, draught-proof and insulate the existing chimneys.

Figure 36 Traditional chimneys, some with added cement render.

Figure 37 Temporary removal of chimney to rebuild bricks.

Figure 38 Repointing of bricks with lime-based pointing after removal of cement render.

Figure 39 Almost completed chimney, with existing cement render replaced with lime render.

3.3.4 *ROOFLIGHTS*

Rooflights can be a pathway for heat loss, however the upgrading traditional rooflights generally involves some loss of historic character. Older rooflights should be maintained in good working order. If a rooflight has reached the end of its working life it may be replaced with a modern rooflight that matches the existing in material and profile as closely as possible. As rooflights differ from windows in detailing and design, it will often be possible to incorporate a double-glazed unit. New, small double-glazed rooflights are available off the shelf. Light shafts leading to a rooflight should be insulated in the course of providing roof insulation.

The addition of new rooflights may be desirable where light is required within the attic space, however the number, design and location of new rooflights must take account of the character of the building and may require planning permission. Rooflights with a low U-value and good airtightness characteristics are recommended to reduce heat loss.

Figure 40 Historic skylights and lanterns, such as this fine example, should be well-maintained but are rarely suitable for thermal upgrading.

Figure 41 This modern double-glazed skylight allows access to a concealed valley gutter for maintenance inspections and cannot be seen from ground level. It also lets additional natural light into the attic space below.

3.4 FLOORS

Traditional buildings in Ireland were typically constructed with either a suspended timber floor or a solid ground floor commonly built of packed rubble and earth, tiles, bricks, flagstones, terrazzo or concrete. It is relatively easy and thermally beneficial to insulate a suspended timber ground floor, but it can be technically difficult, expensive and disruptive to insulate a traditional solid ground floor. Options for insulating traditional suspended and solid ground floors are discussed in the next two sections.

3.4.1 *SUSPENDED TIMBER FLOORS*

Insulating suspended floors from beneath is often the easiest and least disruptive way of installing insulation between the floor joists as it does not require the careful removal and reinstatement of existing floorboards, however, access can be an issue. If the solum (the subfloor area under the floor joists) is less than 600mm in height, it may be easier to insulate the floors from above. Maintaining solum ventilation after insulation is very important to remove excess moisture and ground gases such as radon.

Preparation

If insulating from below, access will need to be gain to the solum area, which will need to be cleared of debris. Joists should be checked for rot, especially where the meet the walls.

If insulating from above, furniture, floor finishes and certain fixings such as kitchen or bathroom units will have to be removed. As the floorboards will need to be removed, care must be taken not to damage the boards if they are to be reinstated (Figure 42). If the building is a Protected Structure, the floorboards should be discreetly numbered and relaid in the same place and orientation after the insulation works are complete. Where possible, the reuse of boards that are in good condition is recommended to avoid waste. Skirting boards may need to be removed and reinstated to make it easier to form airtight seals along the edges. The condition of joists should be assessed before insulation is installed.

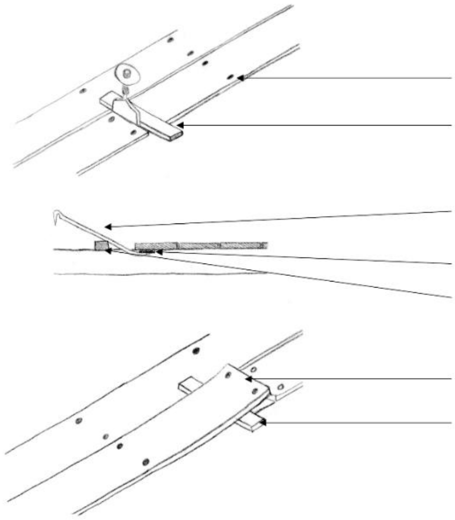

Figure 42 Recommended method to carefully remove existing floorboards.

It is best to ensure that adequate cross ventilation is provided in the solum area before insulation works begin. If air bricks already exist, care must be taken to avoid covering or damaging them. Additional air bricks may need to be installed and ventilation cores may need to be drilled through any support walls to increase cross ventilation. The addition of insulation between the joists can increase the risk of decay to the timber if proper care is not taken to ensure adequate air flow. Additional air flow through the solum, in combination with airtight membranes, has been shown to be effective in helping to reduce indoor radon levels in buildings.

The same advice for electric cables and pipes in unheated loft spaces or within insulation zones should be followed for any floor insulation works.

Figure 43 Existing ground floor joists exposed and readied for insulation.

Materials

Hygroscopic insulations should be used to reduce the risk of moisture build-up in the timber joists and should be fitted to completely fill the space between joists.

Installation

For insulation from below, semi-rigid insulation such as woodfibre or mineral wool may be easier to fit than soft rolls as they will hold in place better if they are cut or ordered to fit snuggly between the joists. The insulation should also fill the full depth of the joists, which are usually between 125mm and 200mm deep in traditional buildings. The most important aspect is that the insulation is fitted properly and tightly, with no air gaps present.

Vibration on floors through normal use mean that mechanical fixing, such as a mesh netting or windtight vapour permeable membrane, is recommended below the insulation to ensure it does not become dislodged over time. Netting is typically used to hold the insulation in place; however, where excessive wind is a concern a windtight vapour control membrane could be used to minimise heat loss. The mesh or membrane should be stretched tightly and carefully sealed. Cross battens (50mm x 25mm) can be fixed into the joists below the membrane for additional support if required (Figure 44). To seal the membrane tightly against the adjacent wall, it may be required to fix a batten to the wall, around which the membrane can then be wrapped. For walls that are smooth and uniform, the membrane can be sealed to the wall by using a primer on the cleaned wall.

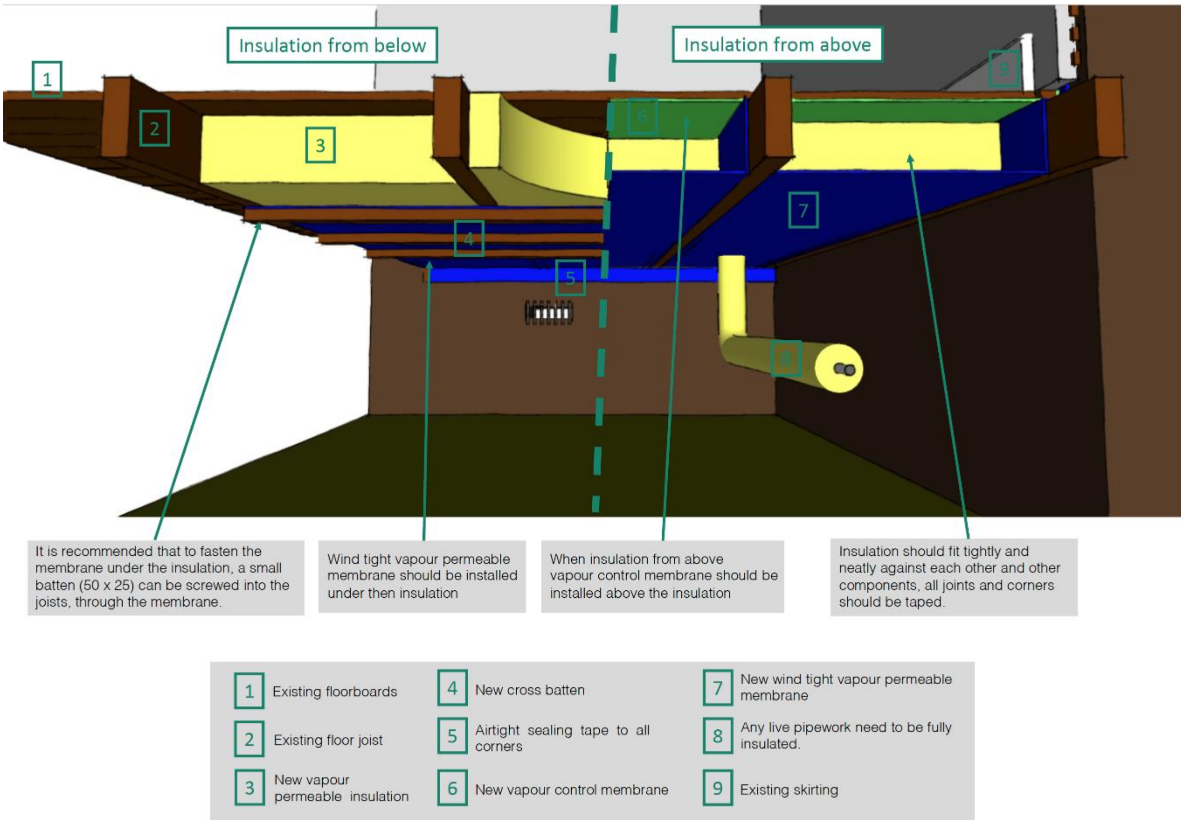

Figure 44 Typical suspended timber floor insulation. At the right, works from below, and ate the left works from below.

If insulating from above, the airtight vapour permeable membrane should be draped between the joists to hold in the insulation in place. The membrane roll should run in the same direction as the joists and should be tightly fitted so that it does not sag. A small batten can be fixed to the lower edge of the joists on both sides, creating a small ledge for the insulation to rest upon.

Sealing the membrane against the wall is very important – this can be done by fixing a batten to the wall, around which the membrane can be wrapped. The small gap between the batten/membrane and the wall can be filled by tightly stuffing insulation material in the gap or bedding it on mastic.

In this case, soft rolls or loose-fill materials can be used as the insulation does not need to hold itself up. When the insulation has been installed, a vapour control layer should be installed between the insulation and the floorboards to reduce the movement of air and vapour from the room into the floor. If space allows, a thin tongue-and-groove fibre board, such as MDF, can be installed between the joists and the floorboards for increased insulation and airtightness.

If access is required to the services in the floor, an airtight access hatch should be installed and insulated as suggested for attic hatches. The hatch must be insulated to the same level as the rest of the floor, to avoid air leakage. Rigid insulation boards may be more useful here, fixed tightly to the underside of the hatch.

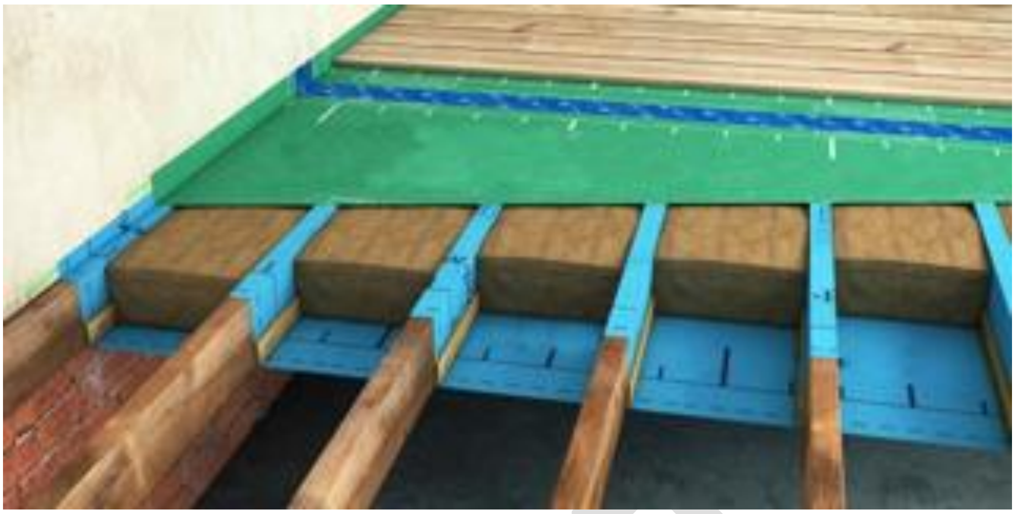

Figure 45 Example of an airtight, vapour permeable membrane (blue) under the insulation (hemp insulation) and the vapour control layer (green) above the insulation.

3.4.2 *Solid Ground Floors*

Traditional solid ground floors tend to be more difficult to insulate. To add insulation to a solid floor requires that the floor level be raised, which may not be feasible or desired. Installing thinner forms of high-performance insulation can be a solution, though it tends to increase the cost of insulation. Additionally, when altering the floor level, other items which interact with the floor may need to be adjusted such as doors, skirting boards, staircases, thresholds, lintels, bulkheads, etc. However, as discussed previously, insulating floors can provide significant benefit in terms of reducing heat loss, therefore it is worth adding even a small amount insulation to solid floors if possible.

Preparation

Depending on the insulation chosen and floor finish, any building elements which interact with the floor such as doors and skirting boards may need to be altered. It is advised that insulation is extended beneath fixed furniture such as kitchens, wardrobes, etc. Areas where air circulation is restricted, like beneath cabinets, tend to have lower surface temperatures and are therefore at greater risk of consequential mould growth. If left uninsulated, the risk of mould growth increases due to a greater temperature differential. Particular attention is required at the floor perimeter where surface temperatures are lowest and the risk of condensation is higher.

Careful assessment of the condition of the floor is required to determine its existing ground moisture resistance and likely ground gas resistance. Where high radon levels are indicated by a radon test result, it may be necessary to replace the existing floor entirely in order to install a radon barrier and standby sump(s), or other appropriate radon mitigation measures. Consideration should be given to reinstating any existing decorative floor finishes following the replacement of the floor. Where excavations for floor replacement expose shallow foundations, care will be needed to ensure that these are not disturbed during the work.

Where floors are replaced, consideration should be given to introducing underfloor heating to improve the efficiency of any heat pump used and to eliminate intrusive radiators.

Materials

Due to dimensional restrictions, thin forms of insulation are often required to upgrade retained solid floors. Aerogel-based products tend to have low U-values and may be suitable to use. It is important to understand that even a small amount of insulation can make an improvement to the thermal performance of the floor.

Installation

Insulation can be added directly over a solid floor if the floor is smooth, level and clean. If not, the floor will need to be levelled with levelling compounds. Insulation material that comes with grooved edges are preferred for a tighter fit. It is important to fill in any air gaps between insulation boards and at the wall junction to avoid thermal bypass.

A vapour control layer can be installed to create an air barrier above the insulation, but this will depend on the type of insulation chosen, the nature of any floor finish provided and the insulation manufacturers' recommendations.

Where a solid floor is overlaid with timber floorboard fixed to battens, insulation could be installed between battens so that the floor level is not raised. If possible, the removal of the battens would allow for continuous insulation over the whole area of the solid floor and would reduce the chance of thermal bridging associated with the battens. Care should be taken when removing the floorboards and battens if they are to be removed. A local authority conservation officer should be consulted if the building is a Protected Structure.

Opportunities may also exist where screeds have been installed in the past, following the removal of earlier floor finishes. It may then be possible to remove the existing screeds and replace them with appropriate pre-insulated floor panels/boards.

After installing insulation, the floor finish can be installed.

3.5 WINDOWS AND DOORS

In traditional historic buildings, original windows were single glazed and most often timber-framed, although metal frames were also used. Original windows should be repaired and retained where possible or if they must be replaced, replacement windows should be of a similar material and style. **In buildings where existing windows and doors must be retained, repairs, draughtproofing, secondary glazing, shutters and curtains can be used in combination to reduce the heat loss.**

Historic Scotland commissioned a study in 2008 to measure the effect of various thermal improvements to the centre-pane U-value of traditional windows.[58] The test window was a typical 6-over-6 timber-framed sash and case window with single glazing, which was in good condition but did not contain any draughtproofing measures. Thermal transmittance tests showed that while draughtproofing resulted in a negligible improvement to the U-value from 4.5 W/m^2K to 4.2 W/m^2K, it reduced air leakage by 86% from approximately 3.5 m3/h to 0.5 m3/h. Of the options tested, **Secondary glazing was shown to be the most effective measure, reducing overall heat**

[58] Baker, P. (2010) Technical Paper 1: Thermal Performance of Traditional Windows, Edinburgh: Historic Environment Scotland. Available at: https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=f3e97c76-b4fa-4c76-a197-a59400be931b.

loss through the window by up to 63%, with timber shutters reducing heat loss by 51%[59]. Of course, the thermal benefit of internal shutters would really only apply outside of daylight hours or when rooms are not in occupation. The full results of study are shown in Table below.

Table 13 Historic Environment Scotland study demonstrating the estimated U-value improvements and percentage of heat loss reduction for a variety of upgrade options for traditional single-glazed windows {Baker, 2010, Technical Paper 1: Thermal Performance of Traditional Windows}.

	Reduction in heat loss	U-value W/m²K	Temperature of Interior (warm) room facing surface °C
Centre of glazing	-	5.4	12
Option 1. Heavy curtains fitted to rail on inside of insulated panel above window	14%	3.2	20
Option 2. Shutters	51%	2.2	19
Option 3. Modified shutters, with insulation inserted into panels and covered with 6mm plywood	60%	1.6	21
Option 4. Modern roller blind fitted at the top of the window case inner lining	22%	3.0	21
Option 5. Modern roller blind as option 4, with low emissivity plastic film fixed to the window facing side of the blind	45%	2.2	20
Option 6. Victorian blind fitted to the top of the recess formed by the window case pulley stiles at the side of the upper sash	28%	3.2	18
Option 7. A "thermal" Duette honeycomb blind manufactured by Hunter Douglas Europe b.v.	36%	2.4	21
Victorian Blind & Shutters	58%	1.8	19
Victorian Blind, Shutters & Curtains	62%	1.6	21
Secondary Glazing System	63%	1.7	19
Secondary Glazing & Curtains	66%	1.3	22
Secondary Glazing & Insulated Shutters	77%	1.0	21
Secondary Glazing & Shutters	75%	1.1	20
Double Glazing	55%	1.9	18

Where original single-glazed windows are still intact, draughtproofing and reversible secondary glazing may be the most optimal and preferential option to improve the U-value of the window. As shown in the table above, secondary glazing in combination with internal shutters (insulation or uninsulated) or heavy curtains can

[59] Baker, P. (2010) Technical Paper 1: Thermal Performance of Traditional Windows, Edinburgh: Historic Environment Scotland. Available at: https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=f3e97c76-b4fa-4c76-a197-a59400be931b.

dramatically improve thermal performance whilst retaining the original window and glass panes (note: these measures are not included as part of DEAP/NEAP methodology) [60].

Figure 46 Typical timber sash windows of traditional buildings.

Materials

If replacing windows and doors, timber is a generally good option in terms of suitability for traditional buildings, thermal efficiency and embodied carbon. For windows, it is important to ensure that the new timber windows are 'dry-glazed' meaning that the glass is not attached with putty and can be easily removed. This improves the window's recycling potential when it needs to be replaced.

Any insulation used around the door and window reveals should be hygroscopic.

Preparation

Windows and doors lose heat through the glass, frames, and any gaps which allow air infiltration, therefore, U-values should not be the only factor considered when looking to reduce heat loss through windows and doors. Glazing manufacturers focus on centre-pane U-values which can be particularly misleading if the panes are held in thermally poor frames (conductive heat losses) or leaky frames (infiltration heat losses) or the window frames are installed without thermal isolation from the structure (installation heat losses). The material conductivity of the frames, the glazing spacers, the frame-to-wall installation and any air infiltration through gaps are important factors which can all be measured and included in the DEAP/NEAP calculation to improve the BER. Bespoke whole window U-value calculations are possible for traditional and upgraded sliding sash windows and can be undertaken by a registered thermal modeller.

[60] Anderson, W. and Robinson, J. (2011) Warmer Bath: A Guide to Improving the Energy Efficiency of Traditional Homes in the City of Bath. England: Bath Preservation Trust & the Centre for Sustainable Energy. Available at: https://www.cse.org.uk/downloads/reports-and-publications/energy-advice/insulation-and-heating/warmer_bath_june2011.pdf.

Thermal modelling can also confirm that works to existing windows do not produce a new or greater contravention of the minimum surface temperature requirement.

Windows and doors also gain and lose heat differently depending on the time of day. For example, south facing windows bring in warmth during the day but lose heat overnight. This loss can be reduced by simple measures such as shutters and heavy curtains. Additionally, removable secondary glazing could be used during the colder seasons and removed during the hotter seasons to allow for heat gains.

In general, where original windows and doors exist, it is preferable to retain them and improve their thermal efficiency. This is not always possible, particularly if they are in very poor condition and repairs may be difficult. Replacement may also be preferred in cases where original doors and windows have previously been replaced with PVC frames, which are not vapour permeable. In these situations, windows and doors can be replaced with new timber frame units that are more suitable to traditional buildings.

It is important to know that window, door or rooflight repair, even extensive repair, does not trigger any requirement to meet modern standards of energy efficiency, however replacement does. Whilst competent joinery shops may be able to produce exact replicas of the existing windows, doors and rooflights these are considered new components and, as such, must comply with current building regulations. Few joinery shops will be able to provide the necessary independent test certification to attest to the new window, door or rooflight's compliance with current building regulations. In these circumstances, appropriate secondary glazing, which does meet current building regulations standards, can be the most direct route to compliance while simultaneously preserving the external character of the building.

Alternatively, when replacing historical windows, doors and rooflights, a relaxation of the U-values required by the building regulations may be acceptable to the local building control authority if it can be shown to be "necessary in order to preserve the architectural and historical integrity of the particular building"[61].

Installation - Retaining windows and doors

The retention of existing windows and doors, where these are original or early replacements, should be the preferred option. First steps should include identifying any air gaps which exist around the windows, doors and their frames which can be draughtproofed, insulated and sealed. Existing window linings should be removed and then replaced after the installation of insulation. The general condition of the existing windows, doors and any timber noggins, lintels and the like should be assessed to determine if any repairs are necessary.

Draughtproofing and secondary glazing[62] should be considered when the original windows are to be kept. Draughts result in heat loss and may make a room feel cooler than it actually is, therefore, draughtproofing is usually the first option to consider for improving the thermal performance of windows in an older building. Draughtproofing will not improve the U-value of a window or door, but it will reduce heat loss by reducing air leakage and the overall aim should be to gain control of the rate of ventilation in the room concerned.

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[61] Department of Housing Local Government and Heritage (2019) Technical Guidance Document L: Conservation of Fuel and Energy - Buildings other than Dwellings, Dublin: Department of the Housing, Planning and Local Government. Available at: https://www.gov.ie/en/publication/80125-technical-guidance-document-l-conservation-of-fuel-and-energy-buildings-other-than-dwellings/. *Paragraph 0.6.6*

[62] For more detailed analysis of secondary glazing, see Pickles, D. (2016) Energy Efficiency and Historic Buildings: Secondary Glazing for Windows: Historic England. Available at: https://historicengland.org.uk/images-books/publications/eehb-secondary-glazing-windows/.

The first step in reducing draughts is to overhaul the windows by carrying out any necessary repairs and ensuring that the sashes or opening lights operate properly within the frame. A window that is in good working order can be fitted with draughtproofing strips. However, with some historic, delicate or valuable windows, it will not be appropriate to cut grooves in the frames to insert draught proofing and expert advice should be sought on alternative methods of upgrading. Typically gaps up to 6 mm can be filled with any one of a variety of available strips including nylon brushes, pile (dense fibre), polypropylene with foam filler and silicone rubber tubes. The fitting of strips varies with some fixed to the surface of the frame and others fitted into the frame by cutting grooves into it. When fitting a product that requires grooves in the frame, care should be taken to ensure that the joints are not damaged in cutting the grooves. These are therefore best fitted by a specialist joiner. Care should also be taken to ensure that existing ironmongery such as handles, catches and hinges will continue to function correctly following draught-stripping and that the colour of the product is appropriate to the window. Dimensions of draught strips should be appropriate to the gap to be filled as larger strips will put pressure on the window and smaller ones will not adequately seal the gap. Strips should have some flexibility in them to ensure they will work with the expansion and contraction of timber between summer and winter months. Metal and timber casement windows can be upgraded with similar type draught strips. Casement windows can also have mastic sealants applied to form a moulded profile when the opening section is closed over the mastic to shape the sealant to the gap. Care should be taken to use a barrier to prevent the opening window from sticking to the silicone and the window frame when fitting the seal.

The quality of available draughtproofing products range widely and assurances should be sought as to the lifespan of a product prior to fitting. In addition, it is important that the product can be removed easily without causing damage to the historic window frame to ensure that it can be replaced when it reaches the end of its life. It should also be noted that flexible draught-proofing strips such as brushes and rubber will cease to operate correctly if painted as part of redecoration works.

Figure 47 A repaired window frame with a replaced style and new parting bead. The timber sash frames have been temporarily removed.

Figure 48 Draught-proofed window frame: brushes are visible on the staff and parting beads, both of which have had to be replaced in order to draught proof. For the brushes to work properly it is important that they are not painted over.

External doors in older buildings may have become ill-fitting over the years and are often draughty. Traditional doors can be draughtproofed in the same way as windows with various draughtproofing strips widely available. The bottom of external doors can also be fitted with a weatherboard providing this can be achieved without damage to a historic door. Letterbox brushes or flaps can be fitted to reduce draughts. For historically important buildings, discreet draughtproofing should be used. In some buildings it may be possible to provide a draught lobby to the interior of the external doors. For a draught lobby to be successful there must be adequate space to close the external door prior to opening the internal door. Installing a draught lobby in a protected structure may require planning permission and the architectural conservation officer in the local authority should be consulted when considering work.

Due to the higher U-value of single glazing, condensation will inevitably still form on the windowpanes during winter months, which may lead in the degradation of the frames. Secondary glazing should therefore be considered in conjunction with draughtproofing to improve the overall thermal performance of the window.

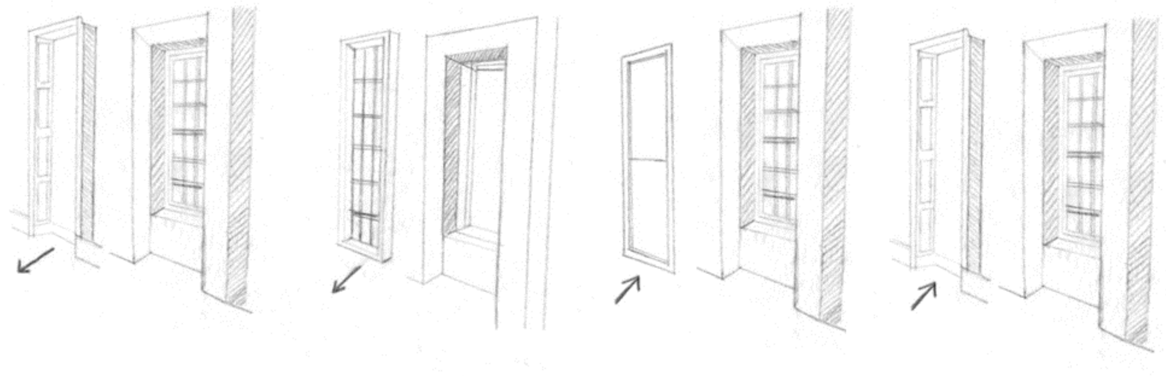
Secondary glazing usually comes in glass, perspex or polycarbonate panels, which are usually installed within a separate frame or onto adhesive/magnetic strips. It is good conservation practice for secondary glazing to be easily removable and reversible to allow for cleaning and removal during summer months to facilitate natural ventilation and cooling. Where draught-proofing measures are installed in addition to the secondary glazing, both measures combined could reduce ventilation and increase the risk of interstitial condensation, in which case operable hinged and sliding secondary glazing units may be more appropriate.

Where the existing glass panes are to be replaced, vacuum-insulating double-glazed panes should be considered to reduce the overall window U-value and increase the surface temperature of the glazing surface. A specialist in traditional window repairs should be able to determine whether the existing frames will be able to handle the additional width and weight of the new double-glazed panes.

To install double-glazed panes, casements should first be removed with the frame left in place. The existing single-glazed panes should then be removed to allow for the cleaning of the timber frame. **The timber may need to be routed out to allow a good fit for thicker double-glazed panes.** The timber frame should be assessed to determine if repairs or reinforcements are required. Hinges and sills should also be assessed and repaired if necessary.

Where possible, existing shutters should be kept and repaired if necessary. Shutters are particularly useful for reducing heat loss during the night. Shutters can be altered to be airtight, reducing air leaks even further.

Window and door reveals should also be insulated, across the width of the reveal before any finishes are added, as they tend to have quite a poor thermal performance. Gaps around the window and door frames can be filled with soft hygroscopic insulation materials and finished with airtightness tapes. If solid wall insulation is being installed, it should extend to the windows and be taped around the windows to ensure airtightness. This may require the temporary removal of shutter boxes. In this case a conservation professional should be consulted. Where external doors have thin panels, the thermal performance can be improved by the insertion of thin insulating boards into the panel recess on the internal face.



1. Carefully remove architraves, skirtings and shutter box. Remove lead paint, repair joinery and prime window casing, sill, etc.

2. Carefully remove window frame and sashes. Remove lead paint, repair joinery, fit draught seals and new weights, and prime.

3. Insulate reveals and refit existing window. Install secondary glazing.

4. Install wall insulation and seal to secondary glazing. Carefully refit existing shutter box, architrave and skirtings.

Figure 49 General process for installing secondary glazing.

Figure 50 Aluminium draught strips can be seen to all sides of this door. The metal part of these strips, unfortunately visible, can be painted but it is important that the flexible sealant strip is not.

Figure 51 Carefully designed bespoke secondary glazing installed as part of Changeworks' Energy Heritage project.

Installation - Replacing windows and doors

High performance double or triple glazed windows can be very effective in reducing heat loss through the glass. Generally, replacement windows should seek to match the original windows in design, form, fixing, method of opening and materials. In replacing sash windows, materials other than timber, such as uPVC, should not be used as they can increase risk of condensation, have a low reuse potential at end of life and low repair opportunity, and are not aesthetically appropriate for traditional buildings. Softwood is typically used in new timber framed windows, which is now often treated to improve durability.

For metal windows, steel replacement double-glazed windows are available, although it can be expensive for individual replacements. Aluminium may be acceptable as an alternative if original patterns and sections can be successfully replicated. Bear in mind that new metal framed windows will need to meet the minimum surface temperature requirements of building regulations.

Narrow-profile double glazing has been specifically developed to allow a more accurate replication of historic window patterns, and vacuum glass is similarly marketed.

Historic stained glass and other decorative glass elements should be retained and may be encapsulated within new double-glazed units fitted to suitably deepened existing reveals or incorporated into new replacement windows.

Figure 52 Examples of vacuum glass installed in the National Library of Ireland

When installing new windows and doors, it is important to make sure that the area around the window or door is properly draughtproofed and well-maintained. If original frames are being kept, the new windows and doors must fit the frame perfectly to avoid any gaps.

In situations where it is not possible to replace all windows or to replace all with high performance glazing, the windows which face north and therefore lose more heat should be prioritised.

3.6 WALLS

According to estimates, external walls are responsible for 35% of heat loss in traditional buildings, therefore the installation of internal and/or external wall insulation could significantly improve the energy efficiency of the building. **Solid wall insulation can be a high risk retrofit option however and should be the last retrofit option**

pursued after all other energy efficiency upgrades have been made. Before internal or external solid wall insulation is installed, hygrothermal risk assessment modelling and in-situ U-value tests should be undertaken to understand the hygrothermal properties and performance of the existing wall and how these will be affected by the proposed insulation. It is also imperative to research, evaluate and understand the integrity of the traditional fabric and finishes to determine what can and cannot be disturbed from a conservation perspective. Solid walls should never be insulated both internally and externally.

Insulating materials and surface coatings must be vapour permeable to allow for moisture within the wall to evaporate through the external or internal surfaces. Water is a conductor, therefore when a wall becomes damp heat transfers through it at a much faster rate compared to a dry wall. Trapped moisture can lead to mould growth and to the rot/decay of timbers. Before any work is done, it is recommended that hygrothermal numerical simulation modelling, such as WUFI, be used to assess the impact of various insulating materials to the walls. Existing finishes like cement render, cement mortar and non-vapour-permeable paints should be removed and replaced with capillary active materials before wall insulation is applied to avoid any moisture related problems in the future.

Historic Environment Scotland conducted in-situ U-value assessments on a number of typical traditional solid wall build-ups in Scotland (see Table). While the exact build-up of the walls may differ slightly in Ireland, their findings demonstrate that traditional solid walls often perform better thermally than commonly thought and all of the walls performed better than the standard 2.1 W/m^{2}K U-value assigned to solid walls in DEAP/NEAP. Therefore, it is recommended to undertake an in-situ U-value assessment (or multiple assessments if different build-ups are present in the building) to determine exactly how much if any insulation is required to meet the energy efficiency targets set for the building.

Table 14 Calculated U-values for traditional walls of varying thickness and composition[63].

Wall Type	Internal Finish	Thickness (mm)	U-value (W/m^{2}K)
Locharbriggs sandstone	Plastered on Hard	550	1.4
Locharbriggs sandstone	Lath and Plaster	550	1.1
Locharbriggs sandstone	Plasterboard	550	0.9
Brick	Plastered on Hard	400	1.1
Craigleith sandstone	Plastered on Hard	600	1.5
Craigleith sandstone	Plastered on Hard	300	2.3
Craigleith sandstone	Lath and Plaster	600	1.4
Craigleith sandstone	Platerboard	600	0.9
Kemnay granite	Plastered on Hard	350	1.7
Kemnay granite	Lath and Plaster	600	0.8
Kemnay granite	Plasterboard	600	0.9
Red sandstone	Plastered on Hard	400	1.3
Blond sandstone	Lath and Plaster	600	0.9

Although the actual U-values of each wall will differ based on their condition, the materials, proportion of materials, location, context, local climate, moisture content and so forth, the following table has been prepared

[63] Baker, P. (2008) Technical Paper 2: In Situ U-value Measurements in Traditional Buildings - Preliminary Results, Edinburgh: Historic Environment Scotland. Available at: https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=7fc3d5f6-5992-4106-92bf-a59400bf430c.

to demonstrate the approximate thermal efficiency improvements that can be expected for a typical traditional solid wall with different types and thicknesses of a selection of vapour open insulations. These figures are based on calculated U-values and no hygrothermal risk analysis was conducted. (*Note: calculations will be completed for the final version of the guidance document.*)

Wall Type	Unimproved U-value	Insulation	Thermal Conductivity	Thickness	Improved U-value	Conditions/Restrictions
solid brick 450mm						

3.6.1 *INTERNAL WALL INSULATION*

Internal wall insulation (IWI) requires the installation of insulation materials to the surface of the internal walls, increasing the wall depth and thus reducing the floor area of a room, which may be a prohibitive factor for small dwellings. IWI will insulate the wall from internal heat sources, thus creating a greater temperature differential between the masonry wall and in the new internal surface of the insulation. It is therefore particularly important that the insulation is vapour open to allow any moisture to dissipate and it is recommended that hygrothermal risk assessment modelling is done before IWI specifications are made.

IWI may be an option for buildings with exposed brick, stone and/or interesting external detailing or for buildings with protected facades. The installation process is disruptive, requiring the reinstallation/repositioning of electrical sockets, radiators, etc. and all decorative architectural features, such as cornices, skirting boards and internal shutters, which may not be allowed in protected structures. Where it is proposed to re-wire the building, sockets and light-switches should be relocated to internal walls where feasible in order to avoid penetration of the newly installed insulation.

If the recommended materials and precautions are followed, IWI can significantly improve the thermal performance of solid walls without introducing moisture related risks. One study has shown that a traditional solid brick wall with an existing in-situ U-value of 1.48 W/m^{2}K can be improved to 0.48 W/m^2 K with just 40mm of woodfibre board IWI[64].

Preparation

IWI should only be considered once the condition of the exterior wall, roof work, guttering and ground areas are satisfactory. Any repair work on the roof, wall, gutters should be first carried out to keep the wall dry. If insulation is added before these components are dealt with, any water that enters can be trapped in by the insulation.

Cement renders and pointing should be removed completely and replaced with lime-based products where possible. Any impermeable layers on the wall should be removed, such as old paint and wallpapers, before IWI is added. It is better to add insulation directly on masonry or on lime-based plaster, which will reduce the risk of moisture build up within the wall.

Efforts should be made to remove any existing pipes, wires and cables to make it easier to lay the insulation uniformly. These should be re-laid on the warm side of the insulation. It may be necessary to remove window boxes and door frames to allow for the insulation of the reveals.

[64] Rye, C. and Scott, C. (2017) 'Understanding the Performance of Solid Walls', Context, Green Retrofit(149), pp. 25-27.

Materials

It is vital that vapour permeable insulation materials are used to insulate traditional solid walls. Suitable materials may include insulating lime plaster with cork or hemp, woodfibre boards, and calcium silicate boards. The selection of materials and determination of their depth should be based on a hygrothermal risk assessment; materials or application thicknesses that fail the assessment should not be considered even if they would achieve the target U-value for the wall. Whichever insulation is used, it is important that the insulation is uniformly applied and that no gaps exist where heat and moisture could bypass the insulation.

Figure 53 Calcium silicate insulation boards installed internally (left) over a mesh layer of skim finish (right).

For walls with uneven surfaces, cork-lime insulation plaster can be used (Figure 54). The insulation can be built up in layers of 15-20mm and then finished with a smooth lime finishing plaster. It has the advantage over rigid insulations in that it allows any unevenness in wall to be dubbed out.

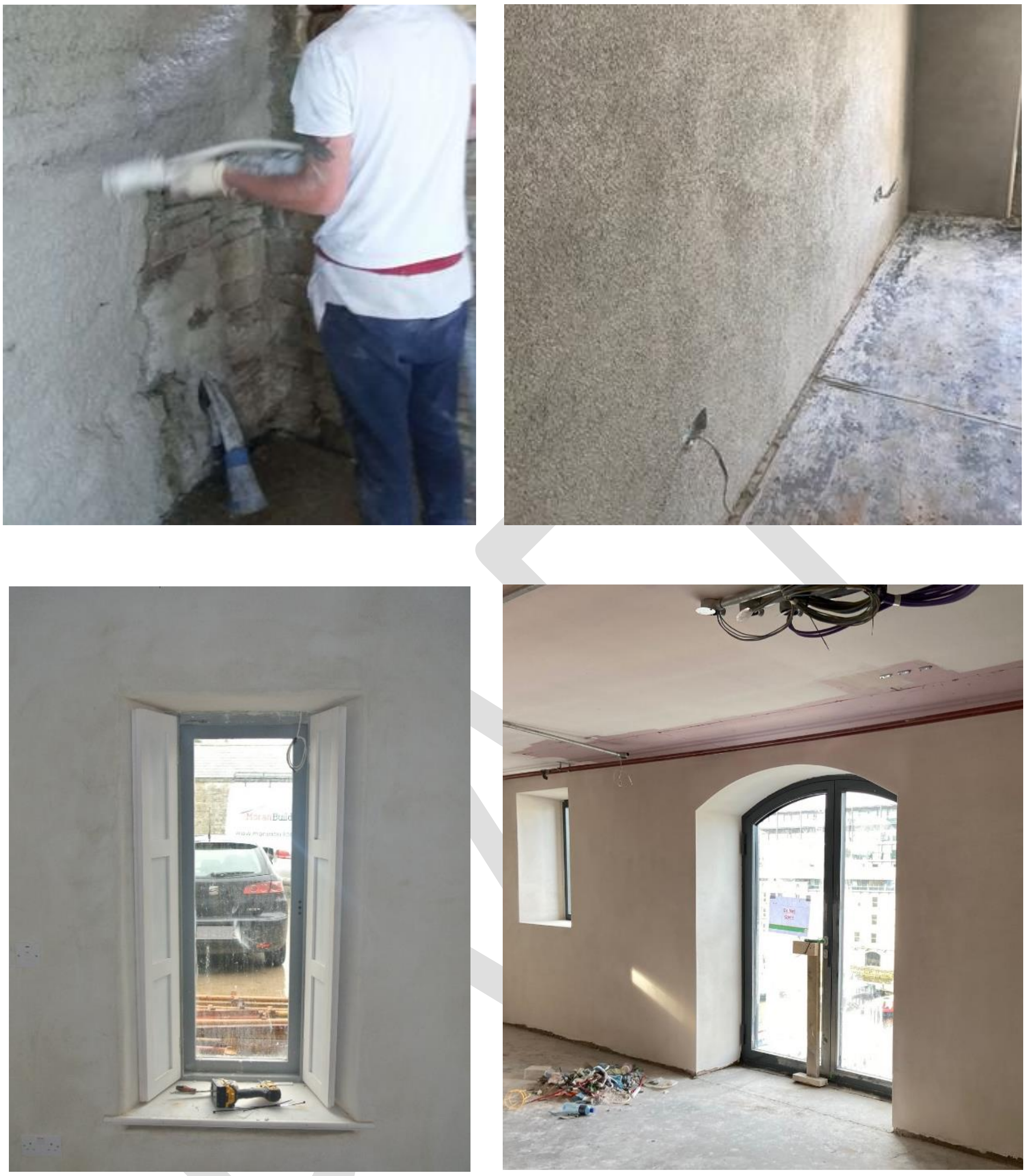


Figure 54 Cork lime plaster insulation sprayed on an uneven wall, providing an even finish to the wall.

Installation

Depending on the wall and the insulation to be used, a plaster layer may need to be added to the internal side of the walls to create a smooth surface for the insulation to be added to.

All reveals should also be insulated as much as possible to keep them from acting as a thermal bypass. To demonstrate this point, one study found that 20mm of IWI with insulated reveals would achieve a similar transmission heat transfer coefficient to 140mm of IWI without insulating the reveals when applied to a 500mm thick solid brick wall in a mid-terrace building[65].

At floor junctions, the insulation should be fitted between and taped against all joists, ensuring an airtight fit. This will require the removal of the perimeter floorboards during the works. It is important that the insulation is extended as far as the depth of the floor, fully filling the intermediated space between floors. In buildings with solid floors, the insulation should go down to ground level, and if possible, below ground level. This insulation should be installed up to and tight to the bottom or starter rail normally used to set the main insulation boards and sealed with a non-setting sealant. In suspended floors the main insulation and render should extend at least as far down as the full depth of the floor joists. Insulation should also extend around window and door reveals and be taped around the frames to ensure a tight fit and uniformity.

Insulation boards should fit tightly and neatly against each other and other components to avoid any gaps or thermal bypass. All joints and corners should be taped. If a membrane is to be added, one should be used that allows vapour to be released through the internal surface at low pressure (variable vapour diffusion resistance), otherwise moisture can be trapped in the wall.

After installation of the insulation and membrane (if required), all services within a service void should be reaffixed. Doing this means that the insulation or membrane are not penetrated which can reduce their overall thermal performance.

To finish, battens can be affixed to the warm side of the insulation onto which finishes such as plasterboard, timber lining or lime/clay plaster can be added. If painting, it is advised that vapour permeable paint is used.

Figure 55 Calcium silicate boards applied to walls and carefully fitted around and between floor joists to ensure continuity of insulation.

65 Marincioni, V., Altamirano-Medina, H., May, N. and Sanders, C. (2016) 'Estimating the Impact of Reveals on the Transmission Heat Transfer Coefficient of Internally Insulated Solid Wall Dwellings', Energy and Buildings, 128, pp. 405-412.

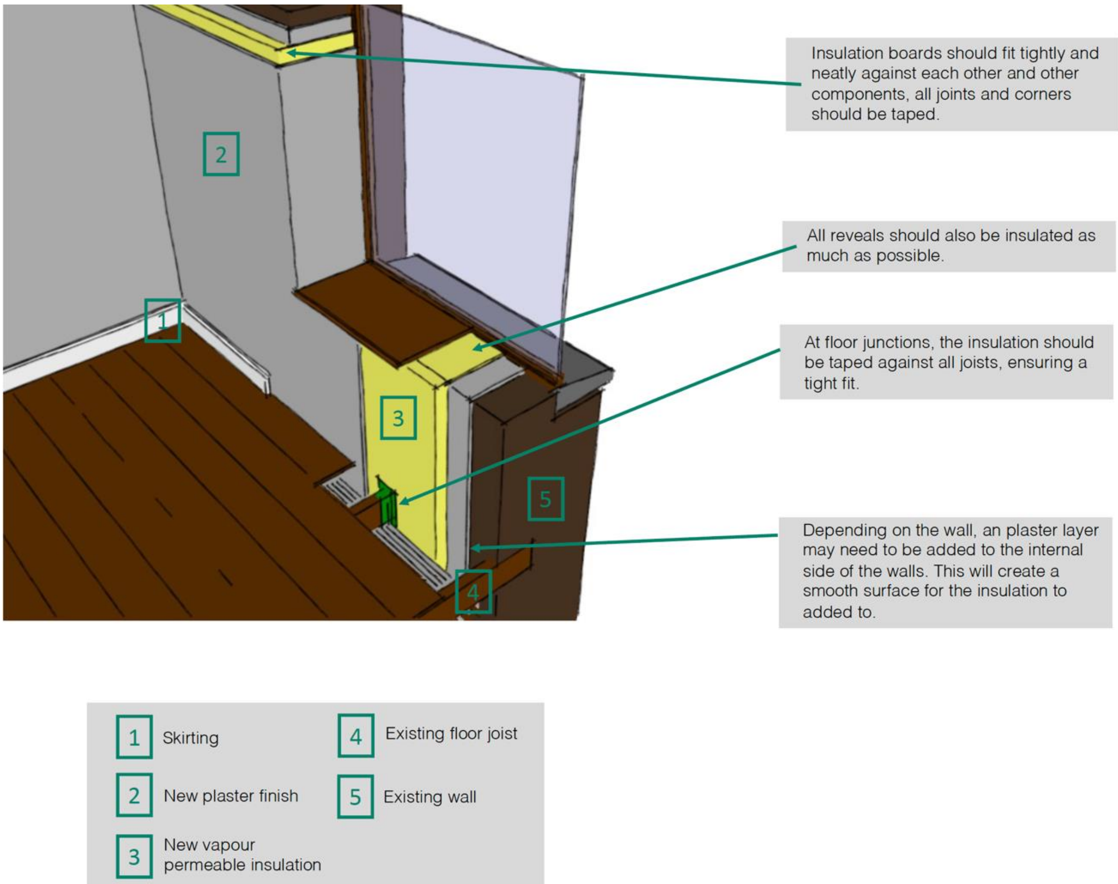


Figure 56 Typical internal wall insulation measures.

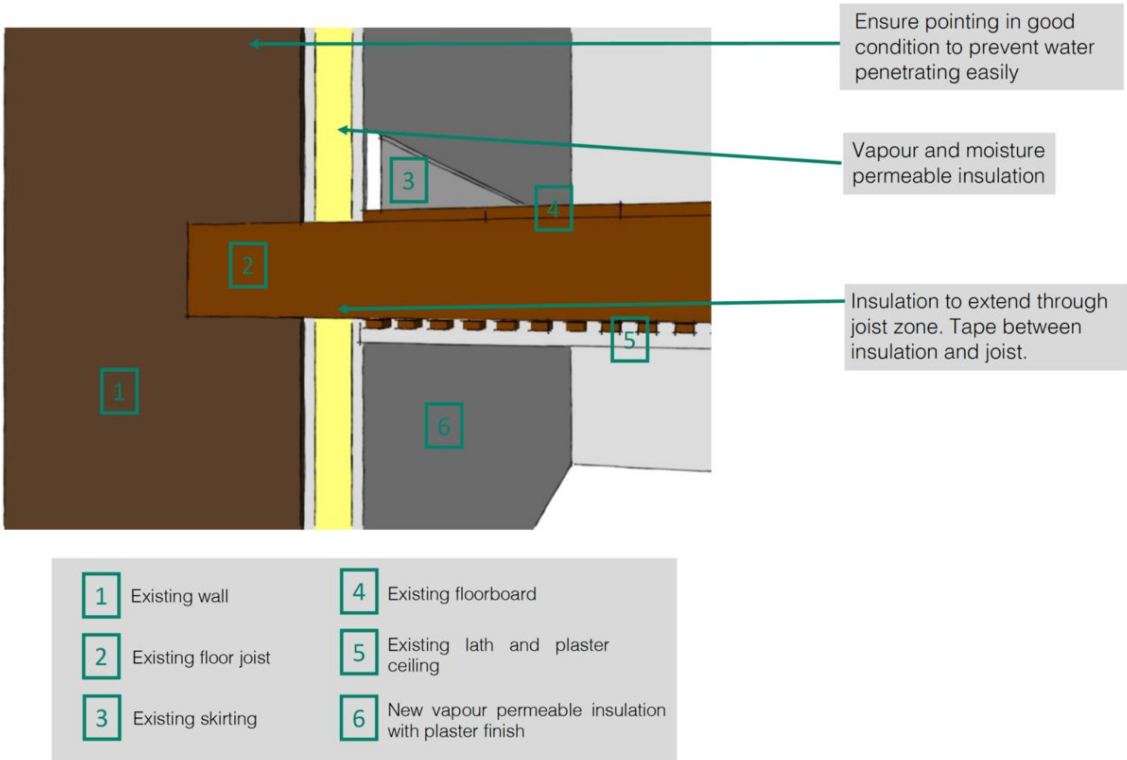


Figure 57 Intermediate floor – Internal insulation.

3.6.2 *EXTERNAL WALL INSULATION*

For traditional buildings that do not have a historically significant exterior, external wall insulation (EWI) may be possible. The installation process for EWI can be less disruptive to the homeowner, but it may require the extension of the roof eaves as well as the replacement or modification of window reveals and sills, door architraves, decorative features, gutters and downpipes, soil and vent pipes and other services.

EWI will insulate the wall from external elements, including the warmth of the sun, but will keep the temperature of the masonry wall closer to internal temperatures. After EWI is applied, the wall will only absorb heat from the internal heat sources and solar gain through the windows. **To maintain safe moisture levels, it is vital that vapour-permeable insulation is used to allow for this movement of moisture from the interior to the exterior**. The risk of cold bridges at eaves level must be considered carefully. Thermal bridge modelling may be required to ensure EWI will not cause thermal bridging at roof and wall junctions.

The following benefits are associated with EWI:

- The exterior walls are evenly covered and 'cold bridging' points are minimised.
- The benefits of thermal mass provided by the solid masonry wall are retained.
- EWI poses a reduced risk of interstitial condensation.
- The building fabric remains heated and dry.
- The internal finishes and room sizes are not altered.

EWI will change the external appearance of a building, therefore planning permission will likely be required for protected structures or those within an architectural conservation area. The local authority architectural conservation officer should be consulted at the early stages of the design process.

Many traditional buildings in Ireland are terraced or semi-detached. In respect to these buildings, careful consideration needs to be given to the risk of thermal bridging at party walls and how these can be eliminated. In addition, external detailing at these junctions needs to be very carefully considered from an aesthetic point of view.

Preparation

Firstly, the utilities and services entering the building must be assessed. Where services enter the building through an external wall, this presents a problem for laying the insulation uniformly and without gaps. Where possible, these services, for example gas meters, should be re-routed to enter the building underground. If this is not possible, efforts should be made to minimise the points of penetration. The services should be installed within conduits to facilitate future alterations. If a gas meter needs to be altered or moved, it is best to contact the gas company in advance of insulation works so that they can safely carry out any alterations.

The condition of the external face of the building needs to be assessed before any insulation is installed to determine if repairs are required. Existing render may need repair/replacement to ensure a smooth surface for the insulation to be added. Non-vapour-permeable renders (cement) should be removed prior to the application of insulation.

It may be necessary to carry out a test of the masonry by a structural engineer to determine if the wall can support insulation in the case of adverse weather conditions such as heavy wind. Downpipes and waste pipes may need to be moved further away from the wall to allow the insulation to be fitted behind them. If these pipes require repair, this should be done before insulation is added.

EWI should be as continuous as possible with the insulation in the roof or ceiling. In cases where there are overhanging eaves, the roof insulation should cover the wall plate, which will make it easier for EWI to meet the roof insulation. This may require the removal of soffit boards. In cases where the roof is tight to the wall, there may not be enough space to join the wall insulation to the roof insulation. In this scenario, it may be possible to extend the lower section of the roof so that the roof insulation can continue across the wall plate to join the wall insulation.

Existing vents should be cleared and more may need to be added to ensure sufficient cross-flow ventilation of the solum.

Any external features such as external lights, aerials, hanging items, etc. should also be removed before any work is carried out. If windows and doors are to be replaced, this should be done before insulation is added so that the insulation can be carefully fitted to and sealed against the frames. Windows should be installed close to or in line with the line of the insulation. The further back from the face of the wall, the greater the gap across the reveal which needs to be insulated.

Materials

As with all the other building elements, insulation materials must be vapour permeable. The movement of moisture from the inside the building to the outside must not be impeded by the EWI.

The thickness of the insulation required will vary depending on the material chosen. It should be noted that a continuous layer of insulation is as important if not more important than the thickness of the insulation. If gaps exist due to poor installation or services running through the insulation, these can act as a thermal bypass and can lead to condensation and mould growth on the internal face of the wall.

The specification of insulation materials and thicknesses should be guided by a hygrothermal risk assessment.

Installation

Once the services have been dealt with and any necessary repairs or alterations to the walls, roof and internal floors have been carried out, insulation can be added. Insulation should be applied according to the manufacturer's guidance. Before any finish is added, the insulation should be independently assessed to make sure that the insulation is uniform and no gaps exist, even in hard to access areas.

It is important that the finishing render is vapour permeable. Lime-based renders are more authentic to traditional buildings. Original features of the building where possible should be replaced / re-formed as far as is possible.

All reveals should be insulated, including the sills. Airtightness tapes should be used on the joints between windows and masonry to avoid air leakage.

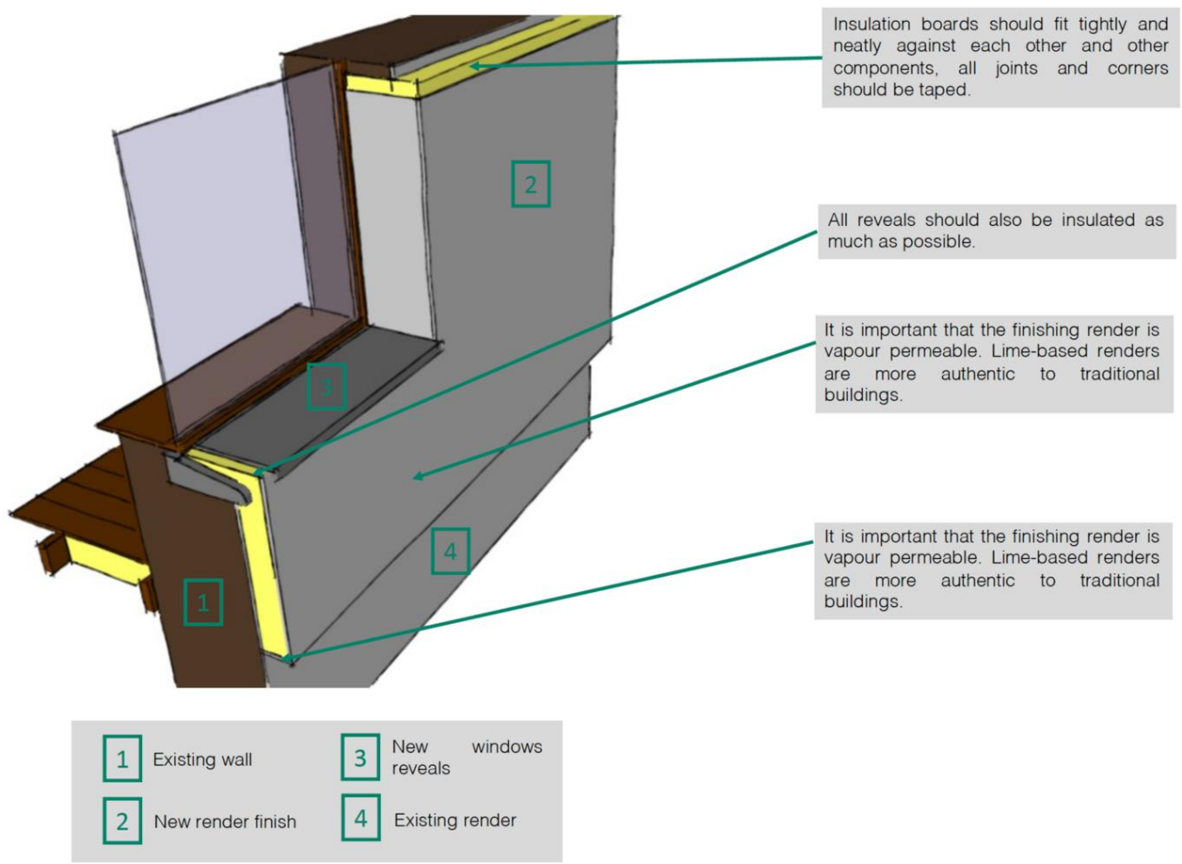


Figure 58 External wall insulation.

3.7 OTHER EFFICIENCY MEASURES

There are opportunities to improve energy and resource efficiency of traditional buildings beyond fabric upgrades. These can help to bring a traditional building's energy rating up to a B2 standard, and as they are typically low-cost and easily implementable measures, they should be considered before considering the procurement of renewable energy.

3.7.1 *LIGHTING AND LIGHTING CONTROLS*

Many traditional buildings were designed for optimum use of daylight, reducing the need for artificial lighting. Upgrading light fittings and controls of these fittings can significantly reduce the use of electricity in buildings, with achievable energy savings typically being higher in non-domestic buildings due to the greater quantity of light fittings and usually higher wattage requirements in comparison to domestic buildings. As such, this is a measure that is often considered when conducting upgrade works to achieve an improved Building Energy Rating (BER). The primary factors to consider when determining the savings from a lighting upgrade are the change in wattage from the existing fittings to the replacements, the yearly running hours and any improvement to the building's Power Factor (PF) when removing magnetic-ballasted fluorescent lights.

At present, **the low price and very high efficiency of light emitting diode (LED) light fittings makes them the best option for lighting**. They offer large reductions in energy usage, longer lifetimes, and brighter and more directional lighting than older incandescent or Compact Fluorescent Lamp (CFL) fittings. Recent developments in LED technology allow a much more varied quality of light than older models, such that the previous advantages of CFLs in formal rooms are largely negated.

Alongside a change of fittings, **installing smart controls offers further reductions in energy usage**. Smart controls may take account of outdoor brightness as well as occupation, to ensure an optimal balance of illumination and efficiency.

Changes to lighting systems are low impact from a building fabric perspective and do not have to be undertaken as part of a wider renovation, however if a major renovation is taking place, Part L specifically requires lighting more than 15 years old to be upgraded in non-domestic buildings. It is also important to identify and adhere to any current standards and regulations which specify the required illuminance (lux) levels, lifetime and wattage of upgrade lighting, prior to selection and installation. An example of such a standard is the European Lighting Standard EN 12464-1:2011, *Light and lighting. Lighting of workplaces. Indoor workplaces*. Then, in terms of energy performance, there is also the European standard EN 15193-1:2017 for *Energy performance of buildings. Energy requirements for lighting. Specifications, Module M9*.

For non-domestic buildings undertaking a major renovation and seeking a high level of control of their lighting (e.g., large offices with complex lighting requirements which change with time), installing Power-over-Ethernet (PoE) low-voltage lighting that utilises ethernet cabling to both supply power to lights and feedback information should be considered. PoE does not offer savings on running costs compared to line-voltage lighting but reduces the embodied energy of cabling as ethernet cabling has less mass than 3-core electrical cabling. The primary advantage of PoE is the high level of data analytics and control it facilitates. For buildings not undergoing a major renovation, PoE lighting is unlikely to offer significant advantages.

3.7.2 *VENTILATION AND COOLING*

Traditional buildings are typically constructed of breathable building fabrics and hence can have high hourly air change rates. Therefore, it can be very beneficial to carry out works to reduce this uncontrolled hourly air change rate. Such works can include draught stripping of external doors and windows (if not already present), installation of room heaters to convert open fire chimneys to flues, and replacement of permanently open vent covers with closable vent covers. Also, if there is a mechanical ventilation system already in place, the owner could consider the installation of a heat recovery unit to recover room heat lost through room ventilation, or room sensors to achieve Demand Control Ventilation (DCV). Prior to any such installations, the efficiency of an existing mechanical ventilation unit could also be considered to ensure the fan components are as energy efficient as possible, i.e. have a low Specific Fan Power (SFP).

To determine the air change rate post upgrade works (and pre if necessary), an airtightness test can be carried out on the building. Carrying out upgrade measures to reduce the hourly air change rate of a building will also subsequently improve the BER as there is less heat loss occurring through ventilation. However, consultation with a building conservation expert may be required prior to undertaking such upgrades.

In terms of cooling, it may be possible to install a heat pump that could provide both heating and cooling. The cooling aspect of a heat pump does not negatively impact a domestic BER, as the BER assessment software only considers the heating aspect of a heat pump, however, commercial BER assessments do consider both heating and cooling. Further guidance on heat pump source selection and possible required heating system modifications/additions is provided in sub section 4.2.1. However, it should also be noted that consultation with a building conservation expert may be required prior to undertaking a heat pump installation.

Either of the above-mentioned technologies are a means of providing energy efficient cooling in a building and consequently, also provide a method of preventing overheating of internal spaces.

3.7.3 *SMART HEATING CONTROLS*

Smart heating controls that respond to temperature sensors ensure more comfortable environments with fewer temperature fluctuations. They may also reduce the run-time of heating systems compared to manual controls, particularly on buildings that are only occupied on weekdays, as temperature requirements for vacant buildings are less. Smart control systems are typical of heat pump installations, as discussed further in subsection 4.3.1.

It is crucial that any smart control system is correctly demonstrated to the building occupier/responsible person, rather than relying on an instruction manual. It is also recommended that any such demonstration is recorded for future reference. Lack of understanding of control systems leads to inefficiency of use, and results in reluctance to install efficient heating systems [66].

Smart heating controls should be considered whenever a heating system is being replaced, or as a part of any major renovation. It is also a measure often implemented to further improve the BER of a building.

[66] SEAI (2020) Encouraging heat pump installations in Ireland. Available at: https://www.seai.ie/publications/Heat-Pump-Adoption.-Maximising-Savings..pdf.

3.7.4 *PIPE INSULATION*

Uninsulated pipework results in higher distribution heat loss and therefore inefficiency in a heating system. Older buildings, including traditional buildings, tend to have wider gauge pipes with greater surface area and higher conductivity, pronouncing the effect.

Insulating this pipework will result in higher efficiency. Consideration should be given to the overall heating requirements, as the original heating system design may have considered heating of spaces from the losses in this pipework. Additionally, insulation methods should be considered from an aesthetic perspective if pipework is clearly visible. What is crucial however is that any cold-water pipework must be insulated in a vapour-tight manner in order to avoid condensation on the pipe surface. In the case of warm/hot water pipes, heat losses from uninsulated pipework are factored in as an internal heat gain in any energy assessment, however an ideal system would include insulation of this pipework also, such that heat emitters are sized to deliver heat to rooms as designed without any drop-off in flow temperature occurring prior to arrival of hot water to the target area. This may be of more importance in buildings with long distribution networks.

3.7.5 *MAINTENANCE SCHEDULES*

Regular maintenance of both building fabric and M&E services results in higher efficiency and prevents problems before they occur. Maintenance is frequently overlooked as an efficiency measure, and is often cost-neutral or better, and reduces the risk of damage. A coherent and well-considered maintenance plan should be a part of any renovation.

Maintenance measures are important to ensure that the energy upgrade measures introduced in the building achieve their target thermal performance. Leaks, blockages and cracks in roofs and walls can all allow moisture into the fabric of a building causing significant damages. Damp patches, mould and rotten joist ends can arise from poor maintenance. This poses a health risk to occupants and increases overall heat loss from the building. Saturated materials conduct heat more effectively and gaps insulation allow heat to escape the building. On many retrofit projects, delays and additional costs are incurred due to uncovering things like rotten rafter or joists ends, damp patches in stonework or rusting metalwork which then need to be repaired. In short, regular maintenance would result in many expensive retrofit projects not being required at all and saving a good deal of money in those that are undertaken. While regular maintenance work costs money, it is rarely as much, in the long term, as the alternative. Much of the basic investigation work can be done by anyone, but it is worth having a professional undertake a more detailed investigation, particularly where access isn't safe or straightforward, or where cause and effect are not obvious.

3.7.6 *FITTINGS AND APPLIANCES*

Depending on the building usage, a significant proportion of energy may go to inefficient appliances and fittings. Timed and aerated hot water taps and showerheads, boiling water taps, and A-rated or better appliances are among measures that should be considered when considering energy usage holistically. For large projects in which an energy auditor is engaged, they will identify opportunities for improvement of energy efficiency among these.

3.7.7 *WATER CONSERVATION*

The implementation of water savings measures may also result in energy savings, particularly in relation to hot water usage which can be a significant consumer of energy in a building. A simple measure that can be implemented to cut down on the usage volume of hot water is installing flow restrictors on taps and showers. The European water label may be used to select water efficient products[67].

Many historic buildings, particularly those in isolated rural locations, also had systems for collecting and storing rainwater. Where old collection systems survive, such as lead or copper tanks in the upper reaches of buildings, water butts or water barrels, it may be possible to bring them back into use as a water conservation measure and for use in activities such as watering the garden or washing cars. Overflow systems, safety systems and protection against flooding should be put in place and maintained.

It is important to note that any proposal to use collected grey water (wastewater from such domestic activities as clothes-washing, dishwashing and bathing) within the building or for use in appliances should be based on expert advice.

Water supply and drainage services increase the risk of damage when used on upper floors, plaster ceilings being most at risk. The greatest risk is from a burst pipe in the roof space, usually caused by an uninsulated pipe freezing during the winter months. To prevent this, **all water service pipes outside of the insulated envelope of a building should be sufficiently lagged.**

[67] The European Water Label available at: http://www.europeanwaterlabel.eu/.

4 INTEGRATING LOW-CARBON AND RENEWABLE ENERGY SOURCES

As opportunities to improve the fabric of traditional buildings may be limited due to technical, aesthetic or regulatory reasons, and other efficiency measures may still result in a building energy rating lower than a B2 (see 3.7), provision of electrical and thermal energy from renewable sources is an important consideration when seeking to decarbonise our building stock. Besides reducing your energy bills, **these systems can improve the energy rating as well as the asset value of the building/home, increase marketability and increase occupier comfort and wellbeing.**

Treatment of existing heating systems is an important aspect of considering new systems. As stressed previously, suitably qualified professionals should be engaged before proceeding with any change to an energy system, heating or electrical.

Under TGD Part L, any building undergoing a Major Renovation (more than 25% of the building envelope) must be brought up to a cost-optimal level - see Section 1.3. In non-domestic buildings, this entails a specific requirement for the upgrade of heating systems more than 15 years old.

4.1 DEALING WITH EXISTING HEATING SYSTEMS

Treatment of existing systems for heating will both influence and be influenced by the choice of a new heating system.

Key questions that should be addressed include:

1. Does the system consume fossil fuels (oil/gas) and how can these be eliminated completely? Over what timeframe?
2. Can the fabric of the building be improved to reduce heat waste and widen the choice of heating solutions?
3. Can the supply of heating be incorporated into the existing heating infrastructure?
4. Is the heating distribution system (radiators and piping network, ducting network, etc.) dated and near end-of-life expectancy?
5. What changes to the heating infrastructure (e.g., zoning, radiator sizing, circulation pump replacement) will be required for the new heating system?
6. How thermally efficient is any existing infrastructure (e.g., pipework) and where can this be improved?
7. How does the existing system interact with ventilation in the building, and how will the new system change that interaction?
8. What footprint does the existing plant take up, and will the new plant require additional space? Is a plant room required and is that possible in the confines of the structure?

4.1.1 *PLUMBED HEATING SYSTEMS*

Heating and ventilation systems in traditional buildings are often well suited to the requirements of the building fabric. Heavy cast-iron radiators, in particular, with their high thermal mass and therefore moderately slow response time, are well suited to avoiding thermal shock in traditional building fabric. Modern heating systems, particularly **heat pumps, are capable of using these cast-iron radiators, though due to the low temperature operation, significant additional radiator capacity may be required alongside these original pieces.** Additionally, these original systems may suffer from problems relating to compatibility, silt accumulation, and general pipework degradation due to corrosion over time. An assessment of compatibility is therefore required to ensure that these original pieces can be retained. Typically, in older type houses, the plumbing network consists of 'gun barrel' piping manufactured from steel. Due to the ferrous nature of steel, 'gun barrel' piping is prone to corrosion over time and is less durable than its plumbing counterpart, copper, which is now more commonly used in developing plumbing networks. Also, the use of existing 'gun barrel' piping with standard brass plumbing fittings requires specific joining fittings to be utilised. Therefore, in deep retrofit scenarios where major works are being carried out on the plumbing system, the 'gun barrel' piping should be removed and replaced with more modern piping throughout. If the piping is concealed, it should be drained, disconnected from all water sources, and left in-situ until subsequent fabric works permit removal.

4.1.2 *Open Fires*

Open fires are highly inefficient heating systems, at around 30% efficiency. Additionally, they impact the ventilation and thermal performance of buildings, as discussed earlier in the document. In some cases, blocking the flue to prevent passive airflow will be necessary to ensure the airtightness requirements of the building are met. In other cases, when more technically preferable heating systems are not possible, a wood-burning stove may be a viable option for the heating system of a building, in which case the existing flue should be adapted for this purpose. Wood for stoves is considered carbon negative due to the carbon sequestered during the growth of trees, however the source of biomass in all cases, including wood for burning, is essential. Wood should be locally sourced from sustainable forestry in all cases and of low moisture content but preferably should not be kiln dried. Additionally, burning wood, especially wet wood, emits high levels of particulate matter, affecting air quality inside and in the local area of the building. These include sulphur oxides (SO_x), nitrogen oxides (NO_x), and carbon monoxide (CO), the emissions of which are higher when combustion occurs at lower temperatures, as in open fires.

Spring-loaded chimney caps are available for installation as a mitigation measure for passive airflow through the chimney of an open fire. These allow flues to be sealed when not in use and to be set to provide a pathway to atmosphere for the by-products of combustion when the fireplace is in use.

Any room with a combustion appliance, e.g. a fireplace, must have a suitably sized permanent ventilation opening so that the free area is sufficient for the appliance installed. Where works in an existing building involve sealing up existing air infiltration pathways, such works may constitute a "new or greater contravention" of the safe operating conditions of the combustion appliance. Alternative means of providing sufficient permanent ventilation may be required to protect occupants from exposure to the toxic by-products of combustion. In energy calculations every chimney is assumed to have its own vent, which is permanently open, whether the chimney is in use or not.

Room-sealed combustion appliances take their air from an uninhabited ventilated space within the premises, or from the air outside the building through an external air vent on the rear of the appliance, and hence, do not require the installation of a permanent wall vent within the room. As a result, they can deliver considerable energy savings over open flued combustion appliances. Further guidance is available in TGD Part J.

The choice of heating system is discussed further in Section 4.2 below, and existing open fireplaces should be considered carefully, both to ensure that they are being treated correctly from the perspective of energy and ventilation, and to preserve historic grates and fire surrounds, which may be of cultural significance.

4.2 CHOOSING AN APPROPRIATE ENERGY SYSTEM FOR YOUR BUILDING

A traditional energy system such as open fires or original heating systems, while often well designed at the time of construction, is rarely an optimal solution to continue with when retofitting a building for energy efficiency. Both the source and the distribution of heat must be considered, and this should be done in the context of the associated emisions from heating, which are a very large proportion of the total emissions in builidngs. Electrical energy usage should also be considered, both for heating and for other uses. **Efficiency measures as outlined in Section 3.7 should be considered first, with on-site renewable electricity generation being utilised where possible.**

Emissions vary between fuel types, and are typically measured in grams of cardon dioxide per kWh of energy used (gCO_2/kWh). The emissions for most forms of energy will remain static over time, while those for electricity will reduce dramatically as the grid is decarbonised by renewable electricity, and those for gas will reduce marginally as biogas and possibly green hydrogen are introduced into the gas network.

The emissions (CO_2 emissions only) associated with fuel types[68,69] commonly found in traditional buildings are:

Table 11 Carbon Dioxide Emissions by fuel type[68,69].

Fuel Type	**Emissions (gCO_2/kWh) (NCV)[68]**
Diesel (e.g. for generators)	263.9
Petrol (e.g. for generators)	251.9
Electricity (2019)	324.5*
Fuel Type	**Emissions (gCO_2/kWh) (GCV)[69]**
Peat Briquettes	377
Sod Peat	375
Coal/Anthracite	361
Natural Gas	203
Wood Logs (Seasoned)	25
Kerosene	272
Bottled LPG (Propane or Butane)	232

* Updated on a regular basis in response to decarbonisation of electrical grid network.

The electricity grid has experienced significant decarbonisation in recent years, with approximately 40% of current electricity coming from renewable sources. This is set to increase to 70% by 2030, which would approximately half emissions from electricity in that time. The gas network must also decarbonise to meet Ireland's climate targets and newly announced legally binding Climate Action Bill, and Gas Networks Ireland have acknowledged that need, without yet pledging for a specific target or timeframe.

At present, natural gas represents lower emissions per kWh than electricity, however, with the increasing utilisation of renewable sources for grid electricity production, this picture may have reversed by 2030. As

[68]SEAI Conversion Factors 2021, SEAI Statistics. Available at: https://www.seai.ie/data-and-insights/seai-statistics/conversion-factors/.
[69] Table 8: Fuel Data, SEAI Domestic Energy Assessment Procedure (DEAP) Version 4.2.2 Manual 2020, Page 202

natural gas will always remain a fossil fuel and has yet to be subjected to an annual decarbonisation target, installing heating systems which utilise electricity offer a better long-term pathway than systems utilising gas, even before efficiency is considered. **Switching to a highly efficient electrical heating system (e.g., using a heat pump) offers the most effective pathway to decarbonisation of space heating and hot water over a long time period,** and **heat pumps are the preferred solution where possible** in both traditional and non-traditional buildings.

The Intergovernmental Panel on Climate Change (IPCC) notes that because of the complex interactions of the phenomenon of climate change, it is essential to decarbonise quickly, and that emissions reductions over the next ten years will be far more impactful than those over the following ten, etc. It is therefore essential to retrofit energy systems that offer the largest possible emissions reductions over that period, and in the cases where a highly efficient electrical system is not possible, a gas burning system may offer a practical lowest-carbon heating solution. However, it is essential that lock-in to a fossil-fuelled heating system is avoided.

In the medium term, a financial incentive to reduce emissions, in the form of increasing carbon taxes, will also be a driver to install the lowest impact systems possible. Capital costs and running costs remain a consideration across any project. It is not within the scope of this report to fully analyse costs of all systems, however in general it can be said that energy efficient systems are usually more expensive to install, but have lower running costs, reduce carbon taxes, increase occupier comfort, and increase building value in addition to the moral and regulatory drivers to installing these systems.

This section outlines a series of flowcharts for determining energy systems in traditional buildings, outlining the initial questions that should be considered when investigating an energy system, and giving a focus for further design and study. These flowcharts are not intended to be prescriptive or to be a comprehensive guide, and the specific character, architectural context, historical significance, aesthetics, and planning permission requirements should be considered in all cases, as well as both the capital cost and the operational cost of the system, and technical considerations outlined elsewhere in this report.

4.2.1 *CONSIDERING HEAT PUMPS*

As previously mentioned, heat pumps offer one effective pathway to decarbonisation of heating in traditional buildings. The working of heat pumps is discussed in greater detail below, but the first consideration of a building works specifier should be whether a heat pump is an appropriate solution for the traditional building in question, as shown in Figure 59.

The first parameter to consider is the building's Heat Loss Indicator, or HLI, which is measured in W/Km^2. The HLI is a measure of the rate of heat loss from a building through the building fabric and ventilation, based on the building's floor area. The HLI does not depend on temperature, however the actual heat losses at any one time are found by multiplying the HLI by the difference between internal temperature and external temperature. The highest level of heat loss in winter, found by taking the coldest anticipated outdoor temperature and the required indoor temperature, represents the maximum thermal load that the heating system must be designed to meet. Many traditional buildings have a pre-retrofit HLI significantly greater than 5 W/Km^2. At this level, the install of a heat pump would be highly inefficient; to satisfy the thermal demand the pump itself would be oversized and expensive, the distribution system would also need to be drastically oversized, and the operating efficiency of the system would be low, as well as other technical concerns. Fabric improvements and ventilation upgrades can improve the HLI significantly, which improves efficiency and allows for optimal sizing. It is important to note that HLI depends on a building's form factor (total heat loss area/floor area) as well as U-values, with lower form factors resulting in lower HLIs. Therefore, upgrade works to building fabrics are being considered, they should be planned so that the desirable target HLI of 2.3 W/Km^2 or less is achieved.

It is also crucial to consider whether the distribution system of heat around a building can be retrofitted to be suitable for a heat pump system, which operates at a lower temperature than a traditional system, and must be considered carefully regarding sizing, zoning, and flow.

A possible challenge to heat pump adoption will be the electricity supply to the building. Heat pumps above a certain size require a 3-phase connection, and those small enough to be supplied by single-phase power still have a large power demand, which will need to be addressed if electrical demand for the building is already near the Maximum Import Capacity (MIC). This may be especially relevant when the building also has, or is considering, the installation of EV chargers to match the need for decarbonisation of transport. Possible solutions here include increasing the building capacity, installing smart controls to limit EV power draw, and reducing electricity usage through the methods discussed in Section 3.7.

Finally, any heating system has an associated footprint for equipment, and in traditional buildings, where space may be limited, there may not always be a suitable location to place that equipment. Reconsidering the source of heat can sometimes be a mitigation measure here.

If these questions have not provided insurmountable challenges to the installation of a heat pump, Figure 59 should then be considered to look at the source of heat. Otherwise, alternative options for heating and hot water should be considered, utilising Figure 61.

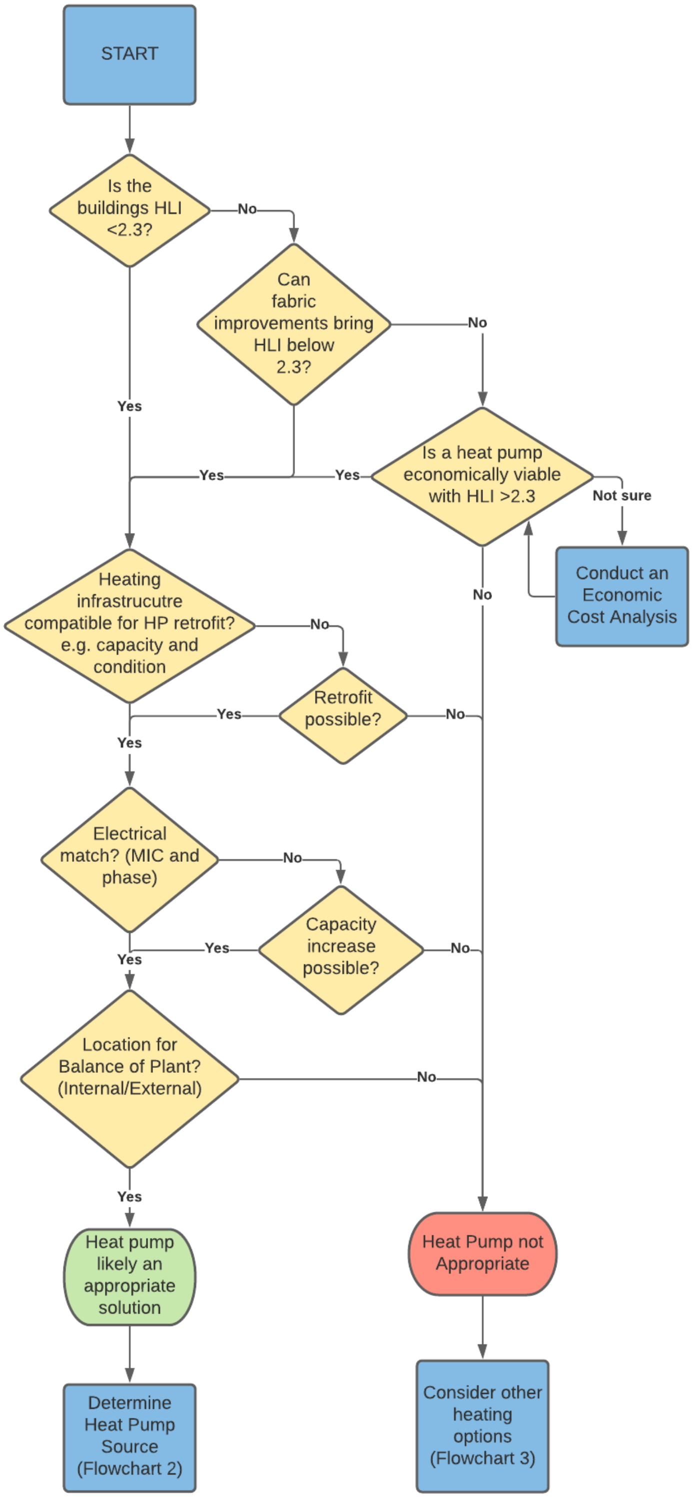


Figure 59 Flowchart 1: Heat pump appropriateness check.

Once it has been decided that a heat pump is likely feasible, the next step is to determine the type and size of heat pump to be employed. The type of heat pump will be determined by the heat source to be utilised, for example, an air source heat pump (ASHP) should be used if the selected heat source is the external ambient air, or a ground source heat pump (GSHP) should be used if the selected heat source is a suitably sized, available ground area surrounding the building. The building owner can use the flowchart provided in Figure 60 as a guide in determining a potentially suitable heat source for the heat pump, however, the services of a professional heat pump specialist should be employed to correctly determine the final heat pump type and design based on a site assessment and building heat loss assessment.

Detailed heat loss assessment methodologies and calculation procedures are provided in I.S. EN 12831:2007 or appropriate software. For the calculation of the design heat losses of a heated space, the following should be considered[70]:

i. Design transmission heat loss: The heat loss through the external building elements (walls, roofs, floors, glazing and thermal bridges), as well as heat transferred between adjacent heated spaces that can be conventionally assumed to be heated at different temperatures.
ii. Design ventilation heat loss: The heat loss to the exterior by (designed natural, mechanical or hybrid) ventilation or by infiltration through the building envelope and the heat transferred by ventilation from one heated space to another heated space inside the building.
iii. Additional heating up powers that occur simultaneously under design conditions in case of intermittent heating; optional item.

The design heat losses should be used to determine the design heat load, which will in turn inform the required capacity of the heat pump system. Heat loss assessments can be revised several times during the design process. **Improvements in the energy performance of the building will reduce the design heat loss and thereby the required capacity of the heat pump system as well as requiring less energy to provide the desired level of comfort on an ongoing basis**. It is important and beneficial to have as many feasible, energy performance improvement upgrades prior to carrying out a heat loss assessment, otherwise there is a potential risk of making an installed heat pump system oversized for purpose and hence less efficient. For this reason, specific mention of the importance and benefit of a building assessment and installing upgrades prior to the consideration of a heat pump installation has been made in the National Standards Authority of Ireland's (NSAI) new heat pump standard recommendation, S.R.50-4:2021, Building services – Part 4: Heat pump systems in dwellings.

Each individual room temperature requirement should also be taken into account in the system design process. Some buildings require higher temperatures, and the system design should also take account of this, but it is important that such requirements be communicated at an early stage in the design process. The typical design temperatures for each room in a dwelling along with indicative ventilation rates are given in Table 12 below.

[70] S.R.50-4:2021 – Building services – Part 4: Heat pump systems in dwellings, National Standards Authority of Ireland Standard Recommendations 2021, page 34

Table 12 Internal Design Temperatures and Indicative Ventilation Rates[71].

Room	**Internal Design Temperature (°C)**	**Air changes per hour**	
		New build	**Retrofit or older building**
Lounge sitting room	21	0.5	1.5
Living room	21	0.5	1.5
Dining room	21	0.5	1.5
Kitchen	18	1.5	2.0
Hall	18	0.5	2.0
Toilet (WC)	18	1.5	2.0
Utility Room	18	0.5	1.5
Study	21	0.5	1.5
Bedroom	18	0.5	1.0
Landing hallway	18	0.5	2.0
Bathroom	23	1.5	3.0

The professional designing the heat pump system should also ensure that the Domestic Hot Water (DHW) requirement of the building will be met by the pump or other DHW system in the building. The hot water provision system should be designed as a minimum to be suitable for the building, with hot water storage capacity and pump capacity also sized accordingly. Additional capacity can be included if and as required based on specific occupation patterns[72]. A heat exchanger unit may be included within an indoor heat pump unit, but in the case that a separate unit is required, its compatibility with both the pump and the distribution system should be carefully checked.

[71] S.R.50-4:2021 – Building services – Part 4: Heat pump systems in dwellings, National Standards Authority of Ireland Standard Recommendations 2021, page 37
[72] S.R.50-4:2021 – Building services – Part 4: Heat pump systems in dwellings, National Standards Authority of Ireland Standard Recommendations 2021, page 39

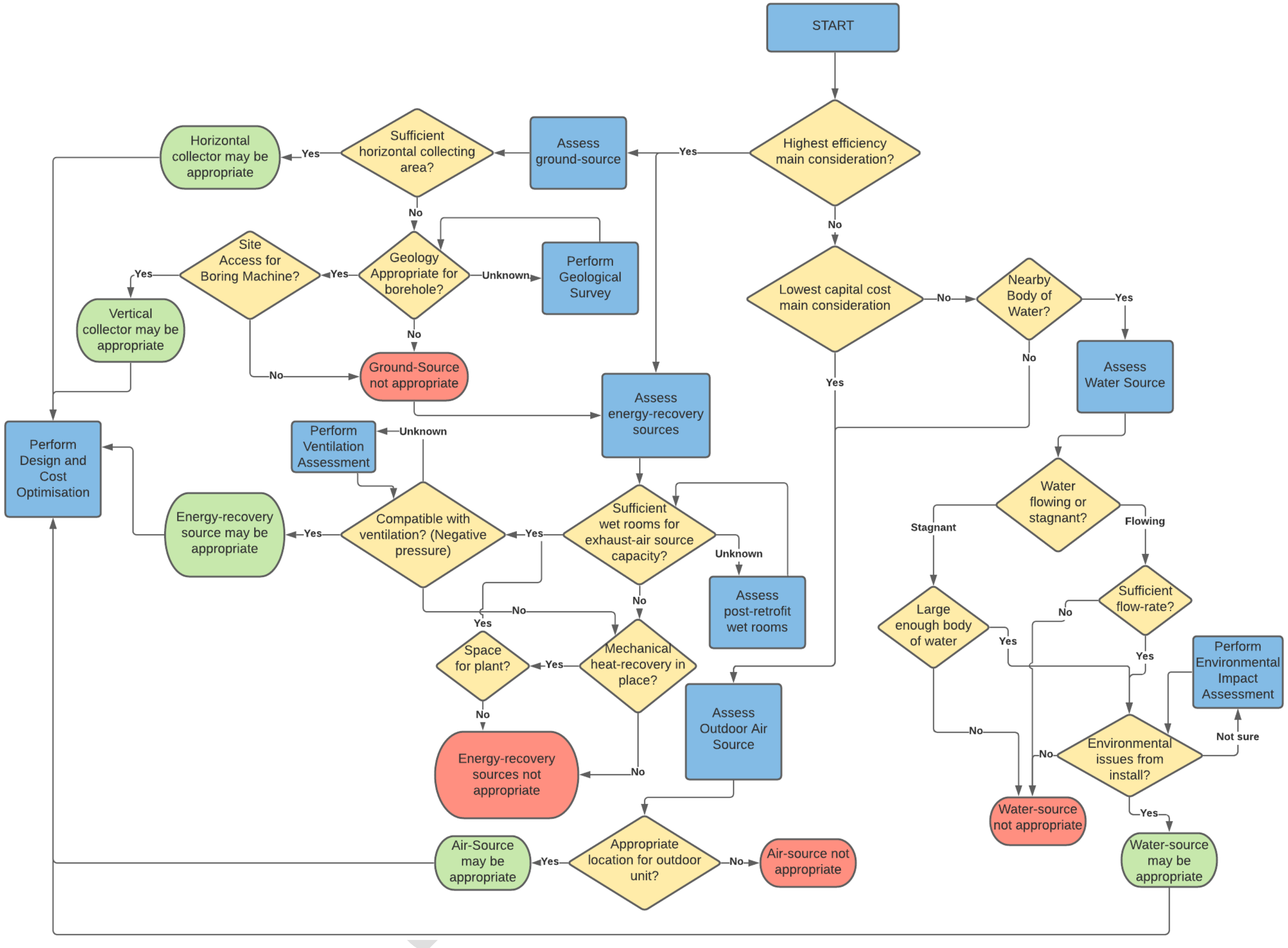


Figure 60 Flowchart 2: Choosing a heat pump source.

4.2.1 CONSIDERING OTHER HEATING OPTIONS

If a heat pump has been determined to be an unfeasible solution, other heating systems must then be considered. The functioning of these systems is discussed below. In each case, the result of the flowchart is not a final system decision, but rather the starting point of further investigation. Each of these systems have different efficiencies, will result in different emissions, and will have varying costs, however this guide aims to steer the building works specifier towards a system which fits well with the building parameters.

Systems which utilise fossil fuels have not been considered here, as these run counter to the aims of emissions reduction, however in the case of biogas CHPs, the running costs of utilising biogas may prevent its utilisation, while the very high efficiency of CHPs may offer significant emissions reductions, even while running on natural gas. However, the significance of these emissions reductions will decrease over time with the decarbonisation of the electrical grid network.

Electrical heating systems other than heat pumps (e.g., HVAC, Infrared Panels, Storage Heaters and Convection Heaters), while not benefitting from the very high efficiency of heat pumps, still offer some long-term potential to decarbonise a heating system, as the grid becomes less carbon intensive. These systems may also have benefits from the perspective of capital cost, as there is no infrastructure for their usage beyond wiring, mounting and controls. For certain budget-limited projects, the capital uplift to go from a low-efficiency electric solution to a heat pump might be better spent on fabric upgrades.

Prior to consulting Flowchart 3 (Figure 61), the presence and condition of an existing heating distribution network (piping or ducting) should be considered. If a distribution system is present but it is dated and near end-of-life, repair and/or replacement works will need to be carried out, which will require the expertise of a qualified plumber and might also require consultation with a conservation specialist if the property in question is a protected structure or located in an architectural conservation area. Otherwise, if the existing system is in good condition, progression to the flowchart shown in Figure 61 should be the next step.

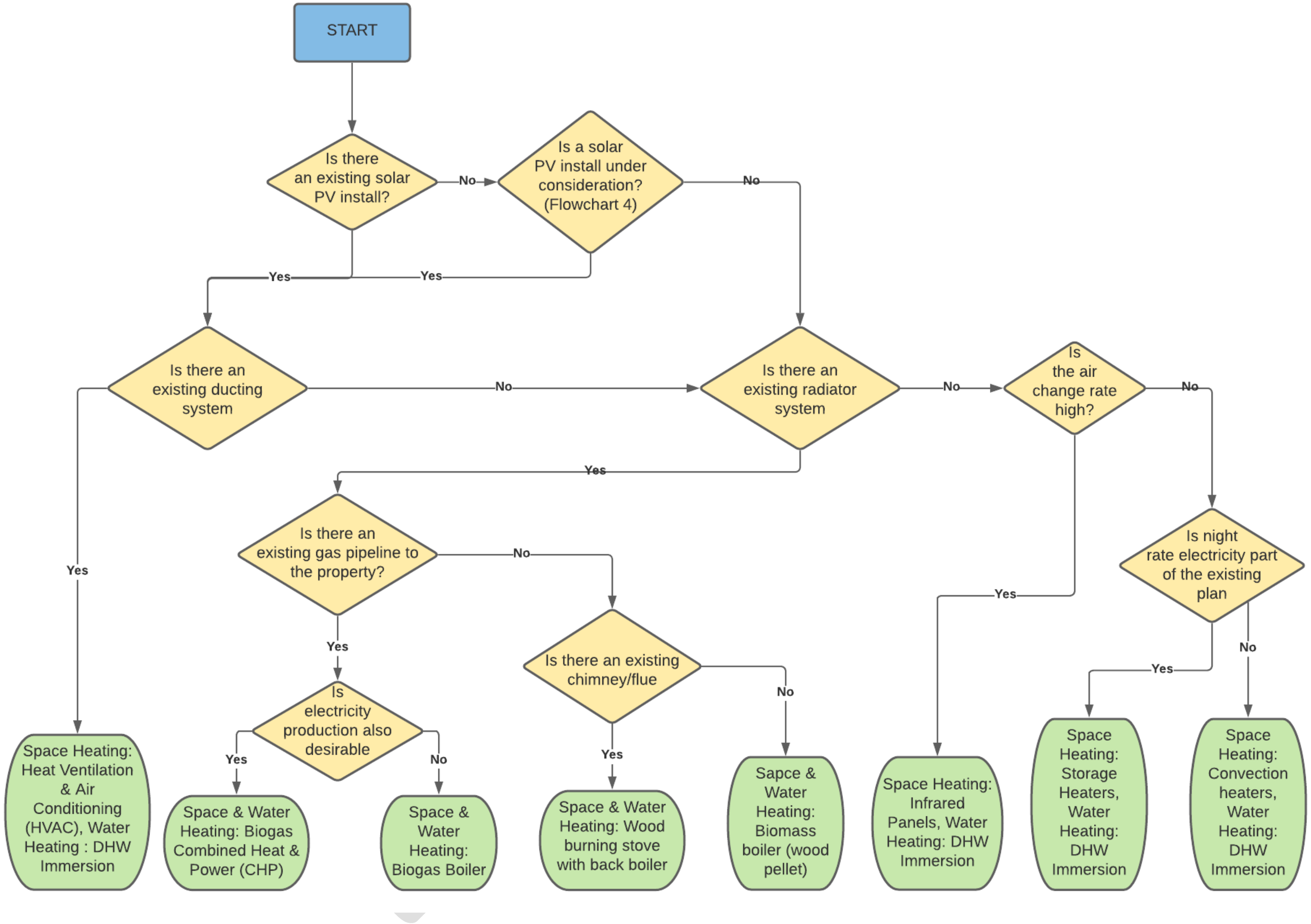


Figure 61 Flowchart 3: Considering other heating options.

4.2.2 CONSIDERING UTILISATION OF SOLAR RESOURCES

Flowchart 4 (Figure 62) focuses on evaluating the potential constraints that can be associated with traditional buildings when considering a solar PV system installation for the utilisation of solar resources. In cases where a building under evaluation is a protected structure or within an architectural conservation area, consultation with a planner or architectural conservation officer is recommended, as appropriate. Assuming the building passes the building evaluation stage, the technical evaluation provided in Flowchart 5 (Figure 63) can then be considered. Flowchart 5 focuses on the utilisation of solar resources at the site, and their potential to generate on-site energy. The chart heavily prioritises solar PV over solar thermal, for reasons discussed further below. Further information and guidance regarding the design, installation, commissioning, and maintenance of solar PV systems will be available in the National Standards Authority of Ireland's (NSAI's) S.R. 50-5:2021, Building Services - Code of Practice – Part 5: Solar Photo Voltaic Systems for dwellings – Design, Installation, Commissioning, and Maintenance which is due to be published and released in 2021.

Detailed technical analysis, financial optimisation, and system design are not addressed here, as there is ample literature elsewhere on these topics. As with the other flowcharts, this guide is intended as a starting point for consideration rather than an ending point.

In all aspects in which solar energy is being utilised on traditional buildings, early consultation with the conservation and planning authorities is recommended to ensure all views are aligned regarding architectural conservation and energy generation.

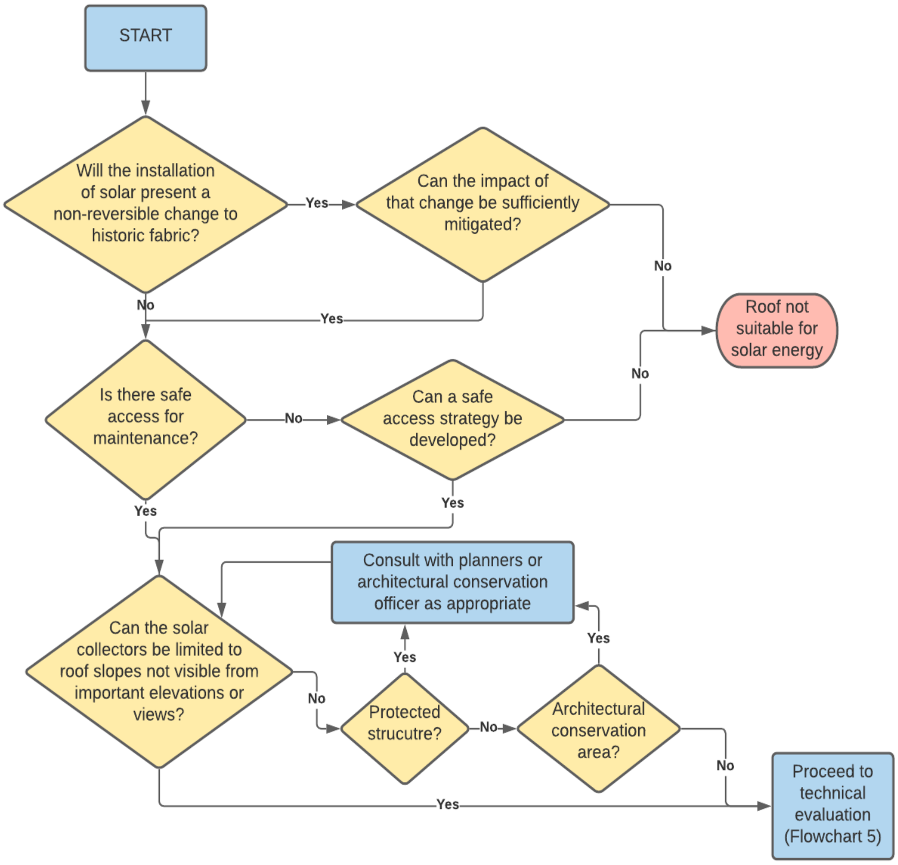


Figure 62 Flowchart 4: Building Evaluation for Solar PV.

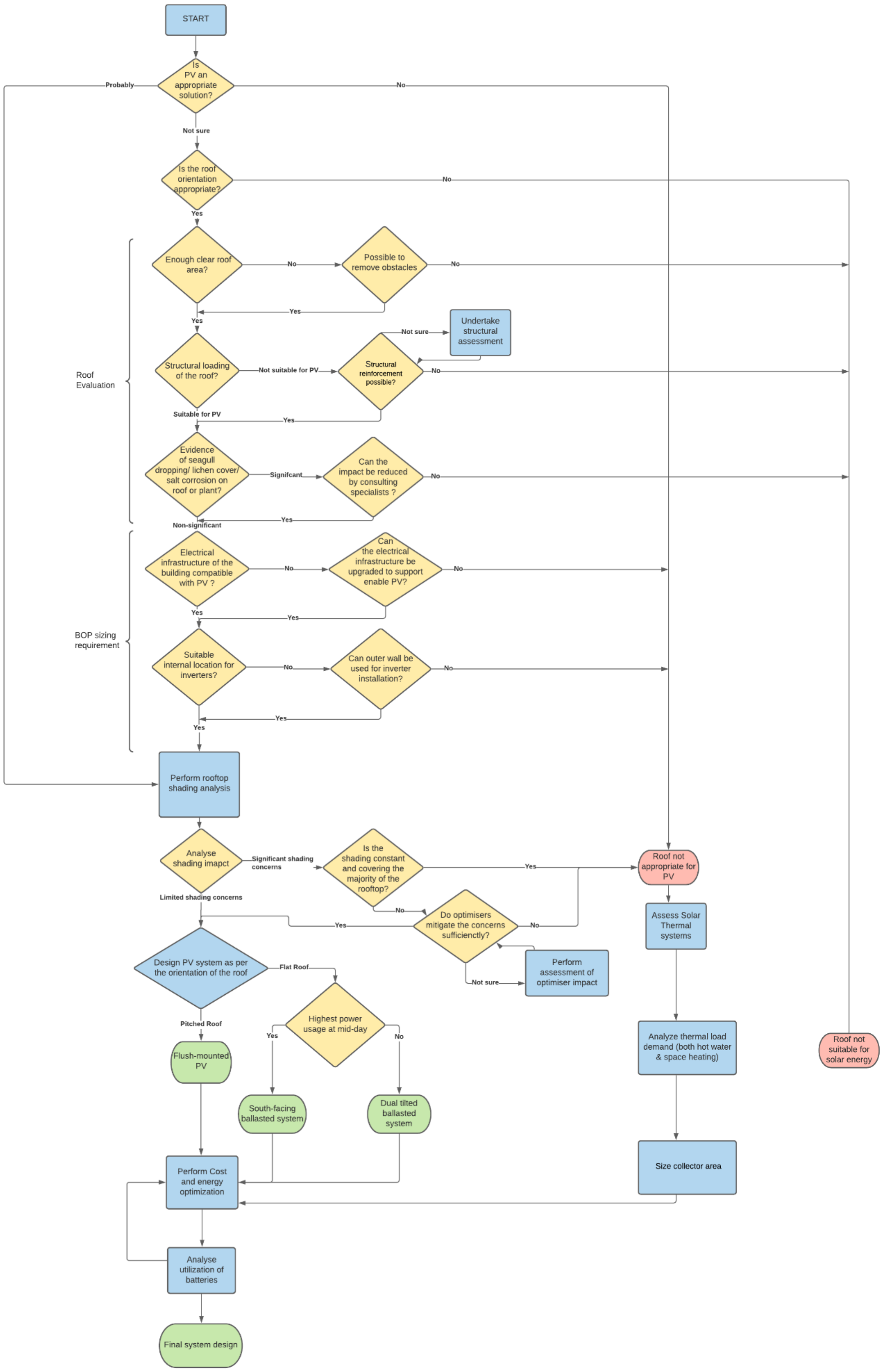


Figure 63 Flowchart 5: Technical Evaluation for Solar PV.

4.3 UPDATE ON LOW-CARBON AND RENEWABLE ENERGY SOURCES APPLICABLE TO TRADITIONAL BUILDINGS

Fabric upgrades can hugely decrease the heat losses from a building, and other efficiency measures noted in Section 3.7 can reduce the operational energy requirements for lighting, heating, and hot water. This will still leave significant energy usage in buildings, at which point it is time to consider renewable energy sources. Renewable energy offers the only possible path to carbon neutral buildings, and in many cases the only path to a BER of B2 or better. This is often the case in traditional buildings, where fabric upgrade measures may be limited by the sensitive nature of the building.

Sections 0 and 4.2 outlined a simple method to determine the starting point of investigation of energy systems, and this section outlines the basic functionality of these systems and the main points to consider in the context of traditional buildings.

Renewable energy may supply electricity, space heating, hot water, or some combination of the three. Each of these is discussed below.

4.3.1 SPACE AND WATER HEATING

Ireland is making significant progress in decarbonising its electricity grid, however a much larger share of total emissions[73] from energy come from heating, and this has proven more difficult to tackle to date. In buildings, the heat load may be separated into the space heating demand and the water heating demand. These loads may be provided by the same, or by different systems in any given building. A renewable or low-carbon energy system supplying a heat demand may tie into the existing system or replace it entirely. In the case of a tie-in, the existing system components must be checked for compatibility and replaced if required. In the case of system replacement, the new system must be optimally sized to ensure it both meets the maximum winter demand of the building and runs as efficiently as possible.

4.3.1.1 HEAT PUMPS

A heat pump is an electrical device that is utilised to transfer heat energy from a heat source (air, ground or water) to a heat sink (internal space of a building). The ratio of electricity consumed to heat transferred is defined by the unit's Coefficient of Performance (COP), with higher COPs always being preferable. Heat pumps in buildings are commonly compared to the workings of a fridge; in the same way that fridges don't create "cold" they move heat from the cold inside to the warm outside, against the temperature gradient, so a Heat Pump moves the heat from the cold outside of a building to the warm inside, likewise against the temperature gradient.

In many buildings, a heat pump may offer the most significant reduction in overall emissions from energy (due to both the lower volume of total energy use and the ongoing decarbonisation of grid electricity), and generally give significant increases to indoor comfort and occupier wellbeing, though their capital cost is often high.

A heat pump may supply space or water heating, or both. In the case of space heating, the capital costs are higher due to the requirements for changes to the heating infrastructure of a building, but utilising Heat Pumps in this way is more efficient, due to the lower temperature requirements for space heating.

[73] SEAI CO_2 Emissions. SEAI Statistics. Available at: https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/co2/.

A Heat Pump's COP is dependent on a number of factors. The heat load of a building, the thermodynamic lift required from the pump, and the type and quality of the unit in question are all important factors.

Correctly calculating a building's heat load should be done in accordance with BS EN12831. It is crucial to correctly assess this metric, as **an oversized heat pump will have a lower COP, and a shorter lifecycle[74], while an undersized Heat Pump will be unable to meet the heat load of a building in the coldest months.**

Temperature uplift is the difference between the temperature of the source (external air/ ground) and the temperature of the sink (internal space). A smaller temperature difference leads to a higher COP. For this reason, a heat pump is run as a low temperature heating system, usually designed to supply a constant indoor temperature without the temperature fluctuations experienced from traditional high-temperature heating systems. This is central to the design of a Heat Pump heating system and results in both a much more thermally comfortable home, and higher system capital costs, as it is not uncommon for heating infrastructure (radiators and possibly the pipe network) to require replacement to allow for this lower temperature system.

The type of heat pump also has a significant impact on both the COP and the system capital costs. When discussing heat pump types, it is sensible to first discuss the source of the heat. There are broadly three types of heat pumps by source: Air Source Heat Pumps (ASHPs), Ground Source Heat Pumps (GSHPs), and Water Source Heat Pumps (WSHPs).

ASHPs take heat directly from the outside air (or, for additional efficiency, from a warm air vent leaving a building), and either pump hot air into an air circulation system, or heat water to be circulated through a radiator system or fed into a hot water tank. ASHPs are typically of relatively low capital cost and offer a relatively simple install without extensive civil works. The COP of ASHPs is typically lower than other heat pump sources, due to lower temperature of the air in winter (and thus greater thermal uplift).

ASHPs require an outdoor unit which should be located with care. The unit must be sufficiently close to the building to minimise losses, but sufficiently far that air can flow around the unit. Drainage or gravel should be provided for condensate, and this should be designed to avoid a slip hazard in winter. The unit should be easily accessible for maintenance and should be located so that the noise it produces is not disruptive to occupants or neighbours, though this may be mitigated by using plants, baffle plates or acoustic barriers. More modern units are also much quieter. ASHPs typically also require an indoor storage tank, controls, and all other heating infrastructure (radiators, piping, manifolds, etc.)

A typical design schematic for an ASHP is shown in Figure 64 below. The unit in this example supplies both space heating and hot water.

[74] O'Reilly, P., O'Shea, M., Hoyne, S. and Hunter, G. (2020) Superhomes 2.0 - Optimisation of Air Source Heat Pump Applications in NZEB Residential Retrofits. Available at: https://lit.ie/en-IE/Research-Development/Development/Energy/Superhomes-2-0-Optimisation-of-Air-Source-Heat-Pum.

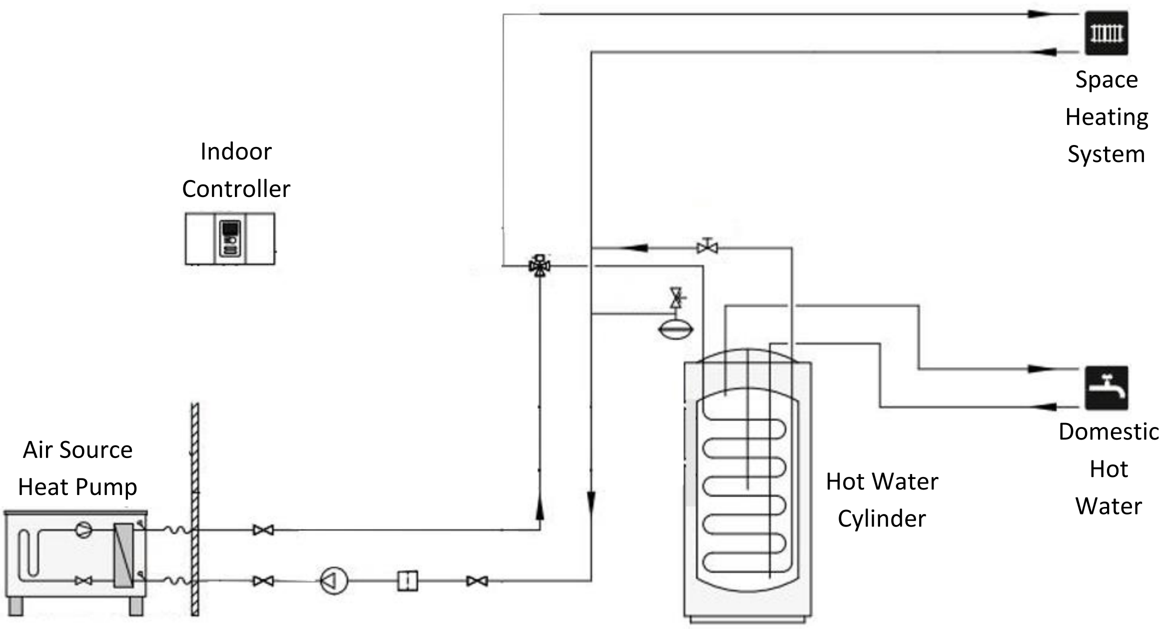


Figure 64 Air source heat pump schematic.

Exhaust Air Heat Pumps (EAHPs) are similar to ASHPs, but instead take warm wet air from wet rooms (bathrooms and kitchens) as their source. EAHPs have high efficiency due to the high temperature of the source, but one design consideration is that they create negative pressure within buildings, therefore they are best suited to buildings with passive ventilation, in which they provide both space heating, hot water and ventilation in a single unit. An EAHP can also take heat from outdoor air, when the capacity from wet rooms is insufficient. In order to function well in a traditional building, the building fabric must be of high performance, and the negative pressure must be accounted for when considering ventilation. Additionally, the installation of ducting work to take air from wet rooms or from outside must be possible, with ducting being appropriately sized so as not to introduce an additional heat load due to excess fresh air intake. An EAHP may be an effective solution when space for an outdoor unit is limited, retrofit of suitable ducting is possible, and the fabric performance is good.

It is also very important to consider the potential for increased radon ingress into a building due to the negative pressure created by EAHP's. In areas where radon gas is present, the negative pressure created inside the building could increase the internal radon concentration where ingress routes are already present. Therefore, it is very important to consider the existing passive ventilation as well as any additional radon control measures as outlined previously in sub-section 0. When considering the retrofit of a building, radon testing pre and post upgrade works is recommended. The map of radon hotspots in Ireland can also be used as a general guide to indicate a potential risk[75], but it is important to note that high radon concentrations in buildings are not limited to these areas. When retrofitting a building in an area deemed to be at risk, it is important to avoid certain interventions which may increase radon levels in the building. Where an initial test indicates a radon level above the national reference level, a radon control strategy must be included in the design of the refurbishment.

[75] Radon Map, EPA: http://www.epa.ie/radiation/radonmap/

Further guidelines on dealing with radon in a building are provided in the Building Regulations Technical Guidance Document C[76] and information on the energy efficient retrofit of dwellings can be found in NSAI's S.R. 54:2014&A1:2019 – Code of Practice for the Energy Efficient Retrofit of Dwellings[77].

Ground Source Heat Pumps (GSHPs) operate by the same principle as ASHPs but draw their heat from the ground. For this reason, they are more efficient, especially in winter when the air temperature drops significantly below ground temperature. This difference in performance is not as pronounced in Ireland as in colder countries. GSHPs can either utilise a horizontal collecting system by digging trenches and laying collecting tubes, or a vertical collecting system by drilling boreholes and utilising the higher temperature at depth to yield better efficiency.

When using a horizonal collecting system, it is crucial to ensure that sufficient collecting area is available. A rough rule of thumb is 2.5 times the floor area of the property in collecting area. Installing a system with an undersized collecting area can result in frozen ground, leading to the pump being out of action in mid-winter when it is most needed.

For vertical collectors, it is important to undertake site-specific testing of geological conditions before boring takes place, and to ensure that a boring machine can obtain access to the property. A vertical collector is more expensive to install but requires less ground area, however boreholes should still be separated by 5-6 metres, dependant on geology.

For traditional buildings, the primary advantages of GSHPs over ASHPs are higher efficiency and lack of a visible outdoor unit, however the requirement for land area will negate their usage in many city-centre properties.

Figure 65 shows a ground source heat pump schematic, as above supplying both space heating and hot water. Additional plant is required here in the heat exchanger, as the fluid circulated through the collecting pipes exchanges heat with the water circulated through the radiator or underfloor heating network.

[76] Technical Guidance Document C: Site Preparation and Resistance to Moisture (2020), Dublin: Department of the Environment, Heritage and Local Government. Available at: http://www.housing.gov.ie/housing/building-standards/tgd-part-c-site-preparation-and-resistance-moisture/technical-guidance-0.
[77] S.R. 54:2014&A1:2019 – Code of Practice for the Energy Efficient Retrofit of Dwellings (2019), National Standards Authority of Ireland. Available at: https://shop.standards.ie/en-ie/standards/s-r-54-2014-a1-2019-877610_saig_nsai_nsai_2749895/

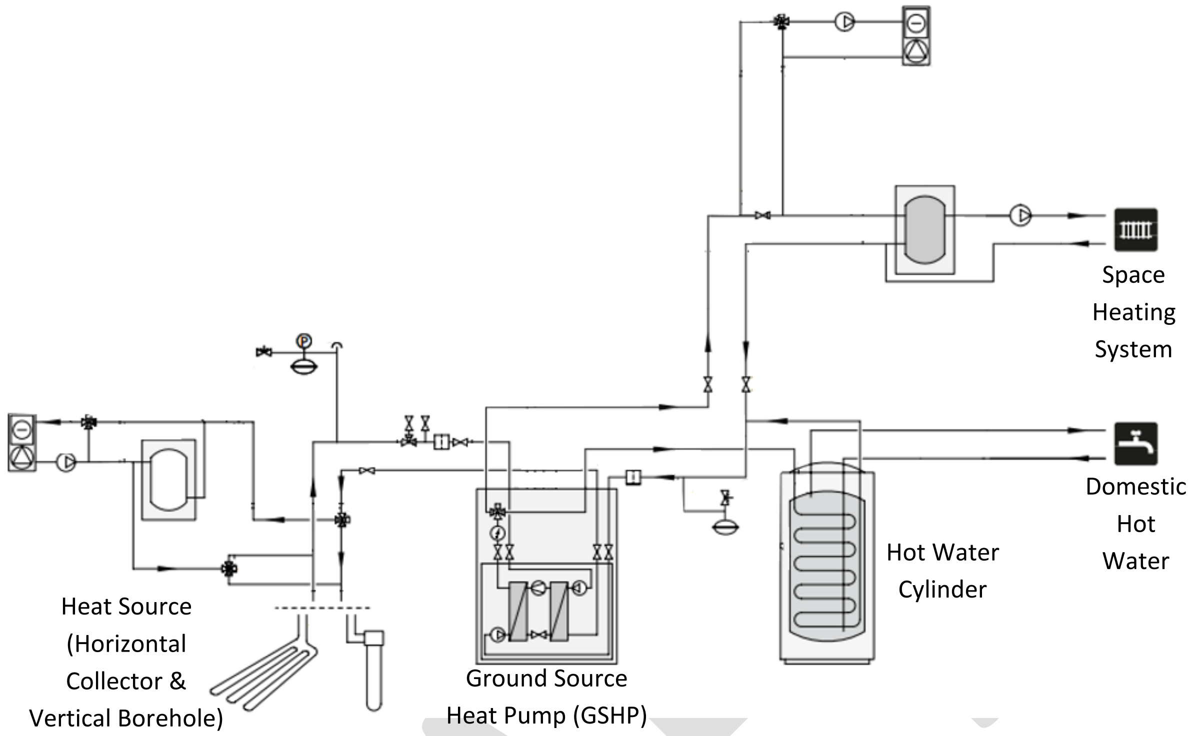


Figure 65 Ground source heat pump schematic.

Water Source Heat Pumps (WSHPs) may utilise ground water or surface water, which in either case may be stagnant or flowing. WSHP are highly efficient, particularly when utilising ground water as a source, however their use is highly site specific, requiring a suitable local body of water. Usage of groundwater for heat pumps must be licensed by the EPA, and its usage is also likely to conflict with usage as drinking water. **It is important to ensure that a building has the best possible thermal performance before installing a heat pump**. Poor thermal performance results in a higher HLI, a larger system capacity, larger radiators, and higher running costs. Uncontrolled ventilation is also very detrimental to heat pump performance, and demand-controlled ventilation is significantly preferable. There is, however, an optimisation point, at which further fabric upgrades offer little return, and the same funds would be better spent on the heat pump.

A heat pump should ideally be installed as a part of a wider renovation.

Legionella control is important to consider when designing heat pumps. Because the system temperature is low, the risk is much greater than in high temp systems. To combat this, the system is typically designed to have periodic raises to high temperature, or with a closed-loop high temperature system component.

Sizing a heat pump is critical: If the capacity is too small, it will not be able to meet the heating demand in mid-winter, too large and it will be very expensive. Heat pump capacity is costly, at around €400-800 per kW, again reinforcing the need for a fabric-first approach to retrofit. A heat pump should be sized to match the post-retrofit heating load. Opinion is currently divided in the industry regarding the use of backup heaters alongside heat pumps. Utilising backup boilers may avoid the need for a larger capacity of heat pump, in some cases, when the additional capacity would only be utilised for a very small percentage of the year, reducing costs and Maximum Import Capacity (MIC) concerns. However, backup heating systems may require deviation from the factory settings of heat pumps and might lead to additional complexity to integrate the system. The authors of this report hold the view that backup heaters may be a valuable edition when the frequency at which they are required is very low and when an existing system is being used to provide the backup (reducing costs) or where there are stringent MIC constraints, and the backup is non-electrical. In any case, the use of backup heaters must be carefully considered at design stage.

Heat pumps require less maintenance than their fossil fuel counterparts, but maintenance should not be ignored. Regular inspections will likely reduce overall maintenance costs.

In operation, low output for long periods is highly preferable over short cycle operation, which lowers efficiency and shortens the life of pumps. Pumps do not need to be "always on" however many are designed in that way. High frequency cycling (multiple times per hour) is especially damaging, and pumps should be monitored post-install to ensure they are operating as intended.

4.3.1.2 Solar Thermal

Solar Thermal is the name given to a kind of solar panels that produces hot water. This is usually used to feed domestic/occupier hot water demand but can also be circulated through a radiator system to provide space-heating and supplement existing space heating systems when the sun is shining. They can also be used for niche applications such as pool heating, though the demand for this is low in Ireland, and particularly in traditional buildings. Solar thermal was once the most prevalent kind of solar energy available in Ireland, but its usage has declined in recent years, primarily due to the comparatively low maintenance, low install cost and high product value of Solar PV; most people install only one kind of solar power, either due to spatial or cost constraints, or because of psychological reasons.

Solar thermal's main advantage is its high conversion efficiency, turning a large proportion of solar energy received into heat energy within a home, however it entails a somewhat more complex install than solar PV, and has much higher operation and maintenance requirements which, if not met, will severely reduce system output after the first years of operation.

4.3.1.3 Infrared Heating Panels

An infrared heating panel takes in electricity and radiates heat. Infrared heating panels do not offer the high efficiency of heat pumps however, their primary advantage is in heating surfaces and thermal masses, rather than the air. This can be advantageous for traditional buildings in which there is highly inconsistent and non-continuous demand for heating, no radiators or air ducts for heat distribution, and frequent air changes that cannot be mitigated.

They have other potential benefits, including low capital cost and the ability to be mounting in a variety of orientations, such as ceiling mounted panels which provide focused heating to the location below them.

As with all electrical heating systems, their associated emissions drop significantly when used in conjunction with solar PV, especially when utilised primarily during daylight hours.

4.3.1.4 Other heating options

Heat Ventilation and Air Conditioning (HVAC)

Heat Ventilation and Air Conditioning systems are utilised to provide acceptable indoor air quality and thermal comfort. This is achieved through the combination of a blower and cooling coils which regulate the internal air temperature to the desired set point temperature. These units also have filters in the system ducting which filter airborne particles from the intake air providing good quality air to the dwelling. Installation of these units can be advantageous for traditional buildings where there is already an existing ducting system in place.

Biogas Boiler

A biogas boiler operates on the same principle as a standard natural gas boiler but instead uses a fuel source obtained through the anaerobic digestion of biomass material, such as, manure, agricultural waste, unpacked expired food waste, etc. Biogas, the initial by-product of this anaerobic digestion process, is first subjected to a process to remove carbon dioxide and trace gases to produce a methane rich renewable natural gas (RNG) known as biomethane which can then be combusted in the burner to provide heat to the boiler. The installation of a biogas boiler is most advantageous in cases where there is an existing natural gas boiler and hence an existing gas pipe network which can be modified to be fed by a biogas store.

Biomass Boiler

A biomass boiler uses a solid fuel combustion process to produce heat and provide it to an integrated boiler unit. The biomass consumed is typically wood pellets which have been sustainably sourced, making these units a greener alternative to the standard solid fuel burning, boiler stove. The installation of these units is most beneficial where there is already an existing wet system for heat distribution in the building, as this typically allows for the old heat source e.g. solid fuel burning, boiler stove, to simply be swapped out for the biomass boiler. The existing system can be either a radiator system, underfloor heating system or a combination of both. It is also beneficial and less cost intensive to have an existing emissions outlet such as a chimney or flue. A range of biomass fuels exist for use in these boilers, with each fuel having particular characteristics that will influence[78]:

i. The choice of boiler type,
ii. The design and requirements for other parts of the system such as fuel handling and storage.

The fuel type utilised is usually determined by the availability, reliability of supply and price, as well as the site characteristics such as the heat demand to be supplied, available space for bulk fuel deliveries, storage and handling, the level of automation required and any local air-quality restrictions. Due to the lower calorific value of biomass fuel (in comparison to solid fossil fuels), consideration should also be made for the longer heating response time. This can be done through the incorporation of smart heating technologies in the heating system design for the building.

Storage heaters with Domestic Hot Water (DHW) immersion

Traditional night storage heaters work on the principle of slowly releasing energy from a thermal store. During the night, when electricity rates are cheaper and the emissions per kWh of electricity used are less, the storage heaters consume electricity to build up a thermal energy store which is then slowly released throughout the following day. This operating principle is achieved through the use of high heat capacity clay or ceramic bricks surrounded by electrical heating elements.

There is also a newer version of this technology on the market known as Smart Electric Thermal Storage (SETS). While these units work on the same operating principle as the traditional night storage heater, they have and added flexibility as the thermal store can be charged at any time to suit electrical grid conditions. These units can also be connected to a cloud aggregation platform which issues optimised charging schedules to the appliances.

[78] Biomass Boilers Technology Guide 2019, SEAI Publications, available at: https://www.seai.ie/publications/Biomass-Boilers-Technology-Guide.pdf

Due to these units being independent of the DHW supply, an immersion heater coil is required to heat the water in the storage cylinder. These heater element coils consume electricity to heat the water to the required DHW temperature (typically to 65°C), with 100% heating efficiency due to the direct transfer of heat energy.

Convection heaters with DHW immersion

Convection heaters consist of an electrical heating element that heats the surrounding air causing it to rise and circulate around the room. This circulation of air creates a convection current that distributes the heat energy to the surrounding space. This unit is independent of the DHW supply therefore an immersion heater coil is required to heat the water in the storage cylinder. These heater element coils consume electricity to heat the water to the required DHW temperature (typically to 65°C), with 100% heating efficiency due to the direct transfer of heat energy.

Wood burning stove with back boiler

In these stoves, sustainably sourced wood is combusted to produce heat. Most of the heat produced is transferred to the water in the boiler which is then circulated through the radiator system in the building to provide space heating. The water is also passed through a 'coil' in a hot water storage cylinder. In doing so, some heat energy transfers to the water in the cylinder, which can then be used for domestic hot water purposes.

4.3.2 ELECTRICAL

Renewables that generate electricity are rapidly gaining in popularity due to the high value of each unit of electricity generated. "Behind the meter" systems which supply a building or group of buildings directly are particularly good investments, as they are reducing grid electricity usage, the most expensive form of energy per kWh. Buildings that currently pay a high cost per kWh for their electricity will find these technologies to be particularly viable, and the savings from these measures may offset the costs of other upgrades.

4.3.2.1 SOLAR PV

Solar Photovoltaic (PV) is a mature, effective and non-invasive technology which provides green electricity directly on site. The rapid decrease in the cost of PV systems over the last ten years means that they are now in most cases a valid financial investment, as well as a measure to reduce primary energy consumption and its associated emissions. Solar PV produces most of its energy in the middle of the day, and much more in summer than winter due to longer daylight hours. For that reason, a solar PV system will never match the entire electrical demand of a building, but rather supplements the grid energy supply with onsite production. A solar PV system typically lasts for 25-30 years, requires a small amount of maintenance, and will require replacement of the inverter (the internal unit which converts DC power to AC power) around halfway through its life.

The most important aspects when positioning PV are the orientation, tilt, and shading. The orientation and tilt determine the annual solar irradiation, which determines output. A south-facing roof pitch will produce the most energy in a year, though an east-west orientated roof is also often viable. North-facing roof pitches should be avoided. Any shading, even partial shading, will significantly reduce the system output, as well as shortening the life of the modules themselves. When rooftops such as extensions or outbuildings (garages etc.) are available, they should also be considered for their solar potential. In many cases this may be the ideal place to locate solar panels, as the roofs are often newer and less aesthetically sensitive.

Most traditional buildings have a geometry which means that their solar potential is limited, and a PV system will only supply a small amount of total power consumption, however in the event of plentiful roof area, care should be taken to avoid oversizing, as the system will become less economical. Microgenerators will be able to export unused power to the grid and receive a tariff, however this will never be as economical as consuming on-site.

One of the concerns of designers looking to utilise solar PV on traditional buildings is the aesthetic impact, especially when the building is located in an ACA or is a listed or protected structure. To combat this, roof valleys are a common area to install solar PV on traditional buildings, as they generally offer the same tilt as an outer-pitch but have much lower visibility. A frequent challenge to this approach is the prominence of traditional chimney stacks, which often overshadow roof valleys. Other strategies may include utilising solar tiles, which are much more aesthetically pleasing but come at a higher cost and lower efficiency.

It is also important to ensure that solar systems are correctly installed. This should be done by adherence to the relevant NSAI Guidance note - Building Services - Code of practice - Solar Photovoltaic Systems [S.R. 50-5 due for publication in late 2021] to ensure the systems are properly secured, risks are minimised, and efficiencies optimised. This S.R. provides practical information and guidance on the design, installation, commissioning and maintenance of solar PV systems in dwellings to ensure that they are designed and installed correctly, meet manufacturer's criteria, are energy efficient and maximise output, whether for use by the dwelling or for export to the public electricity grid.

As mentioned previously, careful engagement with the relevant Conservation Officer or Planning Authority is recommended in all cases when deploying solar PV on traditional buildings, especially if the traditional building is a protected structure or located in an architectural conservation area.

3.2.3.1 Wind Turbines

Wind Turbines function best at large scales and require airflow that has both high velocity and low turbulence. Additionally, turbines create vibration, and must be carefully located to avoid the impacts of noise and shading. For these reasons, their potential for contribution to direct energy provision to the built environment, and to traditional buildings in particular, is very limited. A wind turbine may be a good solution in rural locations such as historic farmhouses, and country manors, and there may be some scope for vertical-axis wind turbines in semi-urban locations with good flow-field conditions.

4.3.3 Electrical and Thermal

As most buildings have both an electrical and a thermal load, a system which can supply both, utilising the same input, can achieve a high efficiency and therefore provide significant carbon reduction. Two such systems are outlined below.

4.3.3.1 Combined Heat and Power

A Combined Heat and Power system (CHP) is in essence a very small-scale version of a gas-fired power plant, located within a building. It typically consumes methane, usually natural gas but can also utilise biomethane, as discussed in section 4.3.4 below, to produce both electricity and heat. Many readers may be confused here, as natural gas is a fossil fuel and produces CO_2 emissions when burned. This is correct, but the main emission reduction of a CHP comes from its ability to utilise the heat output usefully (in a commercial power plant, this heat is often largely wasted).

It is also possible to run a CHP using solid biomass (wood chip/wood pellet), however the fuels are of course not interchangeable, and solid biomass typically requires large storage volumes, which may present a challenge in traditional buildings. Additionally, the source of any solid biomass should be carefully investigated to ensure it is of sustainable origin.

One significant advantage of a CHP is its quick financial payback; gas is much cheaper than electricity, and the ability to produce a high-value output from a low-cost input means that a building can reduce both its emissions and running costs.

CHPs are typically sized to match the entire heating demand for a building, while supplementing the electrical demand. It is important that the building has sufficient electrical demand to match the electrical output, or capacity to increase its capacity (demand response, e.g., though smart EV charging, diversion controllers for hot water) or store any excess electricity produced (e.g., in batteries).

CHPs are most appropriate in cases where a heat pump is not possible, there is an existent gas supply, and there is sufficient demand for both space heating and electricity. Any CHP installation should consider the potential for long-term emission reductions in comparison to an electrical pathway and the building works specifier should be cognisant of technological lock-in.

4.3.4 RENEWABLE ENERGY SUPPLY

Directly reducing energy consumption should always be the first consideration of any project – underlining the importance of achieving the best possible energy efficiency for the building in question. In tandem with this, consideration should be given to the appropriate low carbon or renewable heating system and the appropriate options available outlines elsewhere in this document.

Decarbonisation of both the electrical and gas networks is currently underway and is being progressed by the integration of green energy sources with these networks. The electricity network has experienced the greatest shift towards a greener future as electricity providers now seek to procure their electricity through green energy sources only. Decarbonisation of the gas network, while underway, has further to go in comparison to the electricity network. Green energy sources such as biomethane and green hydrogen both offer pathways toward this decarbonisation initiative, however, both also entail high production costs and currently experience low production volumes at the time of writing. It is recommended that any project planner switches to a green electricity supplier regardless of other upgrade works and investigates the use of biomethane to supply any systems which will continue to burn methane. When considering biofuels in general, the sustainability of their source is an essential consideration. They should be local and created from waste products.

4.4 MANAGEMENT SYSTEMS FOR BUILDINGS

Management systems offer a methodology through which to examine the environmental and energy performance of buildings and organisations through a process of evaluation, monitoring and continuous improvement.

ISO14001:2015

ISO14001:2015 is an international environmental management system, which encourages organisations to improve their sustainability by measuring impact, setting staged targets and monitoring progress. It can be applied to an organisation overall or in parts and can be applied at a building level.

This voluntary standard allows organisations to look at many aspects of their activities and helps them to prioritise actions for maximum impact. It may be certified externally.

ISO50001

ISO 50001 is an international standard designed to offer a practical way to improve energy usage within any sector by developing an Energy Management System. It focuses on energy-specific policies, targets, utilisation of data, measurement and a review and improvement process to ensure continual improvement. Like ISO14001:2015, it may or may not be externally certified.

5 CASE STUDIES

The case studies consist of desktop studies of 7 hypothetical retrofit projects based on available drawings, photography, survey information and general information, the extent of which varies depending on the information available. In general, the following analyses have been carried out with the goal of achieving a B2 energy rating in accordance with the National Calculation Methodology (NEAP or DEAP as applicable), or where impractical for reasons discussed under each case study, as close to B2 as possible.

5.1 OVERVIEW

5.1.1 *OVERALL BUILDING ENERGY ANALYSIS*

Using DEAP/NEAP, an overall primary energy performance coefficient (EPC) and carbon performance coefficient (CPC) for the existing building was determined, with the current BER rating determined from same. To determine the effect of possible retrofit measures on the overall BER (e.g. U-value improvements, different heating sources, installation of renewables, etc.), a number of applicable parametric adjustments and additions were made to each DEAP/NEAP calculation with the aim to achieve a B2 rating as far as is technically and reasonably practicable.

5.1.2 *U-VALUE CALCULATION*

The U-value calculations were based on available survey information. The U-values for all elements were calculated in accordance with IS EN ISO 6946 and BR443 and input to the BER models for the existing and retrofit models. Where no information was available on the construction of any element, default values were taken from relevant tables in accordance with the DEAP/NEAP methodology.

5.1.3 *HYGROTHERMAL RISK ASSESSMENT*

Hygrothermal risk assessment was carried out in accordance with IS EN ISO 15026. As per TGD Part L and Part F requirements, no element can have any risk of surface and/or interstitial condensation. Dynamic hygrothermal risk assessment of traditional construction elements, principally walls, were carried out to ensure no such risk exists.

5.1.4 *INTERSTITIAL CONDENSATION RISK ANALYSIS*

Interstitial condensation risk analysis was carried out in accordance with IS EN ISO 13788. Where the boundaries of interstitial condensation risk analysis in accordance with this standard were not exceeded (thus requiring dynamic hygrothermal risk assessment), roof and/or wall elements were analysed to determine any risk of surface and/or interstitial condensation risk.

5.1.5 *THERMAL BRIDGE ASSESSMENT*

Thermal bridge assessment of junctions between building elements was carried out in accordance with IS EN ISO 10211 and BR497. Linear thermal bridge assessment is crucial in determining additional heat loss at junctions as well as surface condensation and mould growth risk. Where sufficient information on building junctions was available from survey and/or drawings, thermal modelling of all key building junctions was carried out to ensure compliance with TGD Part L with regard to risk of surface condensation and mould growth risk. Default Psi-values of 0.15 W/m^2K were applied to each building as there was insufficient information available to allow for a bespoke y-factor calculation to be undertaken. Significantly different decisions might be made about the energy efficiency interventions required, had a calculated y-factor been possible. It is expected that a calculated y-factor will be possible in many cases where Major Renovation is being undertaken, especially where accompanied by structural repairs or interventions.

5.1.6 *GENERAL APPROACH*

In the following case studies, options have been provided for the insulation of all elements within reason. Hygrothermal risk assessment has been carried out on all case study walls, and target U-value of 0.45W/m^2K has been identified as lowest possible U-value which does not introduce additional risk to the substrates regardless of the method proposed or materials and their thicknesses . In varying situations, applying insulation to achieve U-values beyond this level may introduce such a risk. It is therefore imperative that hygrothermal risk assessment in accordance with IS EN ISO 15026 is carried out with any solid wall insulation project regardless of the target U-value, as the risk is highly dependent on the specific conditions and characteristics of each building which may not be represented in the case studies presented here.

In the case of exposed brick case study buildings and where the brick has always been exposed, an internal insulation system has been selected in order to maintain the outer aesthetic of the building. This is also the case for the exposed granite building. For an externally rendered building, it may be recommended to remove any existing cement-based render and replace with an insulating cork lime render as this is the only solution which maintains the traditional aesthetic of the building and does not result in additional hygrothermal risk. Where the internal finish is a gypsum skim plaster finish on gypsum plasterboard, it is recommended to replace this with an insulating cork lime plaster internally to achieve the target U-value and improve the overall energy performance of the building. If decorative cornices still exist, a calcium silicate board may be preferred due to availability of tapered boards which can fit to insulate behind the cornices without the need to remove them. However, where no such cornices or picture rails are present and the existing substrate (e.g., brick, stone) is to be exposed as part of the project, an insulating lime plaster may be preferred as the most straightforward and cost-effective measure. This can also be tapered away from decorative features, where required. Every project will require such decisions to be made with reference to the specific nature of the building and the goal of the renovation.

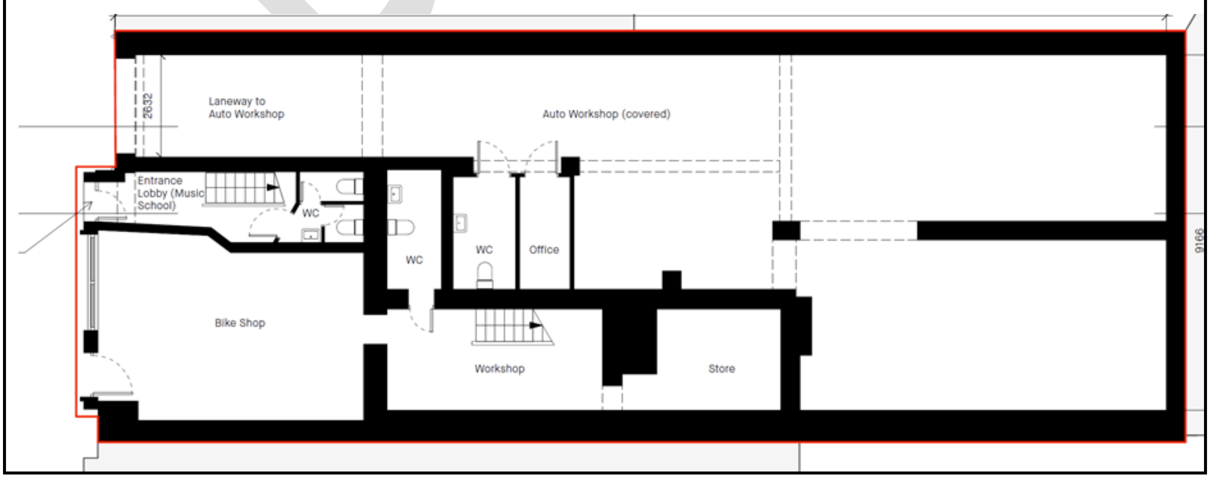
The recommendations for low carbon and renewable energy sources were based on a desktop analysis of available information about the building, its context and location, orientation, the roof tilt angle and likely sources of shading, which were used to generate a solar irradiation density map. Assumptions were made about the energy usage of existing heating systems and potential carbon and energy savings of the recommended system based on the calculated thermal performance improvements of the building fabric.

5.2 MIXED-USE URBAN (BER UPGRADE G TO A1 – RESIDENTIAL)

Figure 66 Front elevation of 19th Century dwelling over retail.

The property consists of 2 dwelling units (apartments) over a ground floor retail unit. Constructed in the mid-to-late 19th century, the site had originally been a mews development and over-the-shop residence with livestock inside the 'barn' structure to the rear. There is no rear access; the property is surrounded by residential and commercial buildings on all three non-frontage sides. The entire building, which is not a protected structure, is under single ownership and is currently served by a single electricity supply and therefore a single MPRN number. The property will be split into separate electricity supplies for each of the two dwelling units and the ground floor retail space. The roof, which consists of a parapet at the front and standard eaves at the rear, provides an ideal installation solution for a solar PV array. The flat roof element of the extension below will provide space for the installation of an air-to-water heat pump system.

The retail unit is entered via a standard retail façade at street level, with side vehicular access to an auto repair shop via a covered lane. Access to the upper floors is via a separate single doorway from the street. The workshop is an unheated space which is completely separated from the thermal envelope of the ground floor retail unit and apartment above.



The building consists of a 550mm solid brick wall constructed in the mid-to-late 19th century. The building is presented in a state of reasonable repair. No significant issues have been identified. The auto workshop is not included in the case study as this is a completely unheated space which is thermally separated from the retail and dwelling units. No beneficial attributes of the unheated workshop space have been applied to the case study building as it is understood that the front access doors will be open during all business hours as well as outside of hours, in which case it is a highly ventilated space.

Status: The building is not a protected structure.

Pre and Post Retrofit BER:

As the building will consist of three separate units with three separate electricity supplies, the existing building has also been modelled as such in DEAP in order to provide direct comparison of the pre- and post-retrofit performance. The residential units have a current BER rating of G, while the retail unit has a current BER rating of E1.

Post-retrofit, the residential units will have a BER rating of A1 (or A3 without the inclusion of the solar PV array), while the retail unit will have a BER rating of A1 (or B1 without the inclusion of the solar PV array). Any solar PV array contribution has been divided equally among the units.

Pre-retrofit:
- Retail: E1
- Residential: G

Post-retrofit:
- Retail: A1 (B1 without solar PV)
- Top floor: A1 (A3 without solar PV)

Energy Assessment

The renovated building will consist of mid-floor and top-floor separate apartments. The mid-floor apartment will also be mid-terrace, in that it will not consist of flanking walls, however the floor of this unit will be over retail and as such will have different heating patterns to this space that must be accounted for in the specification of the floor construction. Works must also comply with any other aspects of the building regulations, including but not limited to Parts B & E for Fire and Acoustics respectively. The top-floor unit has four external walls and a roof.

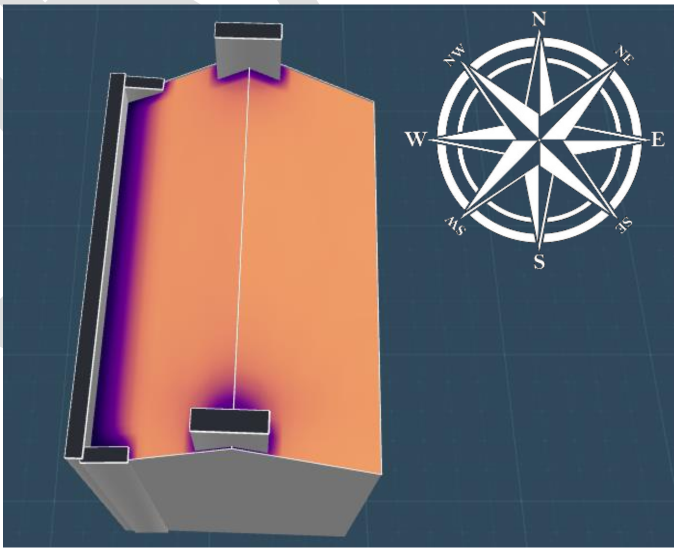
The top-floor unit will also therefore include a number of thermal bridges not experienced in the mid-floor unit which must be considered in any retrofit plan. These will include roof eaves/parapet, gable wall to attic (insulated on ceiling plane), and chimney breast penetration of the ceiling line.

The existing walls consist of a plasterboard layer on timber battens. There is no insulation present, with the exception of mineral wool friction fitted at window jambs, nor is there a

	vapour control layer in the construction. The existing brick is in good condition and generally dry. The external render is c. 30mm and cementitious. The exterior of the building was likely exposed brick and/or lime rendered originally. The intermediate floor consists of softwood tongue-and-groove (T&G) flooring on timber joists over lath and plaster ceilings, which will be preserved and maintained. Compliance with TGD Part B will be required as part of the intermediate floor specification. Additional guidance is available in the Department of Housing document "Bringing Back Homes"[79]. The building is heated by gas boilers and steel radiators. There is no provision for ventilation at present. Windows are double glazed aluminium (non-thermally broken) to the front and rear of the first and second floors. The ground floor retail unit consists of single glazed toughened glass shopfront glazing in a timber frame. There is a small flat roof element over the protruding shopfront which consists of a bitumen asphalt felt on a plywood deck over joists. There is no vapour control or insulation present.	
Element	**Recommendation**	**U-value (W/m^2K)**
External wall	Hygrothermal risk assessment indicates that leaving the external cement render in place will result in moisture accumulation in the wall and therefore, this will be removed. The render will be removed by hand where possible or using a low-impact driver with small chisel head in order to protect and preserve the original brick. To maintain the current appearance of the building, the external facade will be re-rendered using a cork-lime insulating plaster, reinstating the quoins and window reveal beading details. Internally, in order to maintain the existing skim finish appearance, an equal thickness of cork-lime insulating plaster will be applied. If insulation is going to be applied to both the internal and external face of a solid wall, a WUFI calculation should be carried out to confirm that it would present a hygrothermal risk. At intermediate floor level, the floorboards will be removed at the perimeter and the insulating plaster continued between the floor joists. The following process will be followed: 1. Check the condition of the embedded joists at the wall. 2. Install new internal insulating plaster between joists. 3. Apply airtightness system primer, and once cured, apply proprietary airtightness tape/sealant to the full perimeter of the joists. The intermediate floors between dwelling units are non-heat-loss components, and therefore will not require insulation from the perspective of TGD Part L compliance.	0.45
Roof	The roof consists of a cold ventilated structure with hidden gutters and parapets. The second-floor ceiling is a plasterboard fixed directly to the ceiling joists. This will be removed~~,~~ and an airtightness membrane installed with all joints lapped and taped using proprietary system tape. The membrane will be sealed at the external wall perimeter using system sealant. A service cavity batten will be installed perpendicular to the joists, and a new plasterboard applied with skim finish. Following inspection of the joist and rafter condition,	0.12

[79] Department of Housing Local Government and Heritage (2018) Bringing Back Homes - Manual for the Reuse of Existing Buildings. Available at: https://www.gov.ie/en/publication/68a5b-bringing-back-homes-manual-for-the-reuse-of-existing-buildings/.

	replacements/repairs will be implemented where required. The roof will then be insulated at ceiling level using two layers of vapour permeable insulation between and over joists. Ventilation to the roof space will be provided via proprietary roof slate ventilators. It is important to ensure compliance with TGD Part F in order to reduce any risk of condensation in the roof space. Interstitial condensation risk analysis was carried out in accordance with IS EN ISO 13788 and found to be free of risk. There is a very small flat roof area over the WC which is accessed from the ground floor retail unit. This is to be removed entirely and replaced with a warm roof system consisting of a single ply membrane over rigid insulation over a new structural deck.	
Floor	The existing modern concrete floor is uneven and will be removed. The floor will be replaced with a standard structural concrete slab on separation layer on 80mm rigid insulation (PIR with thermal conductivity of 0.022W/mK) on radon barrier/DPM as required, on sand blinding and compacted hardcore. Prior to pour of the concrete slab, a 25mm rigid PIR perimeter insulation upstand will be installed to the full depth of the slab (100mm). This perimeter insulation will provide continuity of the thermal line from beneath the floor slab onto the external wall, as it will be in alignment with the external wall internally-applied insulation.	0.20
Windows	The existing windows (non-original) in the apartment units will be replaced with a timber framed triple-glazed sash system with an overall average U-value of 1.6W/m^{2}K. The windows will be designed in such a manner as to prevent fall risk. Following condition assessment of the shopfront windows, the ground floor shopfront glazing will also be replaced. Providing the timber framing is found to be in good condition it should be left in place, treated and re-painted. The access door will be upgraded to a composite timber door panel with a U-value of 1.2W/m^{2}K. The access door to the rear unheated space will be left unchanged as this door is a security feature only between the streetscape and unheated workshop environment. This door accesses a part of the building which is outside the scope of this case study.	1.6
Ventilation	The building is currently not purposefully ventilated and is therefore not compliant with TGD Part F. Each unit must be individually compliant with this requirement. Due to space limitations, the installation of a whole building mechanical ventilation system will not be possible. The rooms in the units are small in size and the installation of vertical flow and return ducts within the building, incorporating fire dampers at each floor and boxing-in requirements, would sacrifice excessive usable space and therefore will not be implemented in this situation. The units at each floor will instead be fitted with demand control ventilation (DCV) single point systems which are sleeved in cores in the external walls. These cores will be provided at the required points on the external wall as determined by the ventilation supplier/consultant in order to ensure compliance with TGD Part F. These systems involve a constant extract fan whose fan speed is controlled by humidity sensor, with fresh air entering at the wall terminals. A target air permeability value of 3m^3/m^2.hr @ 50Pa has been used in the DEAP energy model and will be the target airtightness value to be achieved.	
Heating & DHW	On its own, this property represents a challenge when it comes to the practicalities of installing an air-source heat pump (ASHP) unit; there is no readily available space to locate the outdoor unit. However, installation could be catered for on a whole building basis with an	

	air-to-water heat pump located to the rear of the building and providing heat to radiators sized at 45°C flow temperature and with time and temperature control by utilising structural reinforcement and mitigation. The rear of the building is fully occupied by the ground floor retail unit, which has a thin roof covering that would not be capable of supporting the weight of a collecting unit. Additionally, there is the consideration of noise, as the rear of the building is surrounded on all sides by other commercial and residential properties, though at a reasonable setback. To address these issues, the roof of the ground floor unit should be reinforced to allow for the load-bearing requirements of an ASHP and fitted with ample drainage to carry away condensate. Sound and vibration dampening is also recommended to ensure that the operation of the heat pump does not disturb the retail work on the ground floor or the surrounding residents. An enclosure around the heat pump with baffling is recommended.
Additional renewables	Although not a requirement on this project, 20 no. 345W solar PV panels could be installed on the roof for each unit facing east/west on either side of the roof ridge. The recommended maximum capacity design of 6.9kWp would yield carbon emission reductions and decrease energy consumption from the grid. The following sub-sections provide a brief overview of the design: Roof description The pitched roof of the building has two elevated chimneys on either gable and an extended roof ledge on the front. There are no major obstacles present on the roof and it is in good condition, with no signs of excessive fouling or lichen growth. Irradiance Map The irradiance map depicts the level of solar radiation and shading on the roof. Darker colours indicate heavy shading, which impacts both the performance and lifetime of PV installations. There would be no significant shading impact from the adjacent buildings as the building under consideration is taller. Only the roof ledge and elevated chimneys will cast some shading on the roof.  System Design The below-mentioned system design has the following specifications: • 6.9kWp system with 20 x 345W solar PV modules • A predicted annual energy production of 5,630 kWh/year

- The system array is split to either side of the roof as shown, with one half (3.45kWp) being supplied to the residential part of the building and the other half (3.45kWp) supplying energy to the commercial (ground floor) part of the building.

SUMMARY

Table 17 Energy Improvement of Mixed Use Urban – Mid Floor.

Options	Mid Floor	Energy Rating	Primary Energy kWh/m²/yr	CO_2 Emissions $kgCO_2/m^2$	HLI
	Existing Energy Rating	G	710.58	132.95	6.42
1	Fabric Upgrade	G	451.21	85.09	2.26
2	Ventilation and air tightness	F	449.06	84.73	2.18
3	Heat Pump Upgrade	B1	75.92	14.93	2.18
4	6 No. PV Panels 2.07 kW	A1	2.36	0.46	

Table 18 Energy Improvement of Mixed-Use Urban – Top Floor.

Options	Top Floor	Energy Rating	Primary Energy kWh/m²/yr	CO_2 Emissions $kgCO_2/m^2$	HLI
	Existing Energy Rating	G	657.16	122.82	6.51
1	Fabric Upgrade	E1	329.01	62.26	1.32
2	Ventilation and air tightness	E1	329.01	62.26	1.32
3	Heat Pump Upgrade	A3	62.87	12.36	1.32
4	4 No. PV Panels 1.38 kW	A1	23.95	4.71	

5.3 NON-RESIDENTIAL - OFFICE BUILDING (BER UPGRADE F TO B2)

Figure 67 Front elevation of converted parochial hall.

This building was constructed in c. 1822 as a parochial hall and is currently in use as an open-plan office space. The building is a protected structure and retains elements of architectural heritage interest both internally and externally, making the decision-making process complex with regard to intervention measures from an energy retrofit perspective. Due to its protected status, the building does not need to comply with the values outlined in TGD Part L, however the building will be renovated in such a way as to maximise energy efficiency, reduce carbon emissions, and deliver occupant comfort and a hygienic environment insofar as is reasonably practicable.

The walls are c. 650mm thick and consist of concrete internally with an external brick leaf. Surveying was non-invasive and therefore the exact make-up of the wall is unknown. For the purpose of analyses, it is assumed that the brick element is c. 220mm on 430mm concrete. The roof consists of slate bedded on lime over battens on a 200mm rafter. The ground floor is a naturally ventilated suspended timber floor, which is not original and is not of architectural heritage importance to the building.
The is currently no purposeful ventilation provided to the building. The windows are a mixture of single glazed timber and metal framed systems, all of which will be replaced. Heating is currently provided via a gas boiler located in an out-building.

Status: Protected Structure

Pre and Post Retrofit BER:

Pre-retrofit: F
Post-retrofit: B2

Element	Recommendation	U-value (W/m²K)
External wall	The external walls are currently plastered on the internal face, with wainscotting up to c. 1.5m internally from floor level. The existing internal plaster will be removed back to the concrete and replastered with insulating cork lime plaster to achieve a U-value of 0.45W/m²K based on a thickness of 60mm. The insulating plaster will be applied in three layers of 20mm, with proprietary system reinforcing mesh applied based on manufacturer’s	0.45

	guidance. The wainscotting will be replaced onto the new internal insulating plaster. The brick-and-mortar joints have been examined and found to be in good repair. There is no evidence of existing issues such as spalling, freeze/thaw cycle cracking, missing mortar at joints, efflorescence, etc.  Figure 68 Concrete wall behind modern plaster.  Figure 69 Spray application of insulating lime plaster.  Figure 70 Internal open plan area.	
Roof	The existing slates will be removed and stored for re-instatement. The existing rafters have been found to be dry and in good condition. In order to preserve the visual aesthetic of the existing roof structure as seen internally, the roof will have 180mm of breathable wood fibre insulation fitted between the existing 200mm rafters, kept flush with the top of the rafter. A proprietary system breathable internal plaster will be applied to the underside of the insulation at a thickness of c. 6mm. Once cured, a colour-matched flexible sealant bead will be applied to the joints of the insulation and the rafters. Over the existing rafters, a 50mm insulating wood fibre sarking board will be applied using proprietary system fixings into the rafter, over which a roofing windtight breather membrane will be installed. A vertical counter batten will be installed prior to installation of new slating battens, and	0.20

	reinstatement of the original slates. This will result in a c. 75mm higher roof finish level, which will require planning consent. Ventilation of the slating batten void will be provided over fascia and at the ridge, which will require the installation of new ridge vent caps in accordance with TGD Part F and for which a suitable architectural product choice will be made. Proprietary over-fascia vents will be installed which include an insect mesh and rodent guard. The over-fascia vents clamp over the roof membrane to allow any water to flow through the vent and into the gutter.  Figure 71 Internal finish of the existing roof with exposed rafters.	
Floor	The existing floorboards are not original and will be removed. They do contribute to the decorative nature of the interior however they are a common pine tongued-and-grooved floor which will either be retained where possible for re-instatement or replaced with matching floorboards. The ground floor is a suspended ventilated floor with brick vents around the perimeter. Where the floor joists are resting on tassel walls and not fixed into external walls, these will be temporarily removed and stored (where original) or assessed for re-use or replacement. The subfloor void will be cleared and tidied where any obvious large debris exists which could either lead to restrictions in ventilation air flow or harbour mould growth in moist conditions. Following reinstatement or replacement of the joists, insulation will be laid over counter-battens to the underside of the joists, or indeed supporting meshing, between the floor joists. A new plywood deck with pre-routed grooves for underfloor heating pipe network will be installed directly over the joists prior to installation of new, or existing reinstated, floorboards, all achieving a U-value	0.18

	of 0.18W/m²K. All joints in the plywood deck boards will be taped using proprietary airtightness sealing tape. This will also be used to seal between the plywood decking and the external walls at the perimeter junction.  Figure 72 Existing T&G Flooring.	
Windows	The current windows are timber framed and single glazed, with an estimated U-value of 5.0W/m²K. The frames are suffering from rot sporadically and the glazing putty is cracked and disintegrated and has not been repaired/replaced over the years, leading to subsequent water ingress over time. Therefore, the windows will be replaced with timber framed double glazed units with warm edge spacers with a U-value of 1.6W/m²K. The entrance/exit door frames are rotting from the bottoms of the stiles due to water absorption, with the door leaves themselves consisting of 22mm softwood timber panelling with an estimated U-value of c. 2.94W/m²K, and will be replaced with a solid composite insulated timber panel door with a U-value of 1.6W/m²K. The insulating lime plaster will be returned in to meet the frames, which will be sealed and taped for airtightness onto the opes in advance of the plastering.	1.6

	 Figure 73 Timber framed window (copyright lambstongue.ie).	
Ventilation	There is currently no controlled ventilation system in place. Two cores will be made in the external wall of the low-level storage which runs the length of the building, with appropriate heritage grilles fitted externally. The ducts will be sufficiently spaced apart to avoid any mixing of exhaust and fresh-intake air in accordance with manufacturer's recommendations. The unit will be installed by a certified registered installer and commissioned independently and validated by an NSAI-accredited ventilation validation specialist in accordance with any and all requirements of TGD Part F. The mechanical heat recovery ventilation (MHRV) unit will be installed in the storage space, providing sufficient room for regular replacement of filters as well as routine maintenance of the unit itself. A power supply on an individual circuit will be provided to the ventilation unit. The MHRV unit will have a minimum heat recovery efficiency of 75%. Fresh air supply grilles will be located along the wall to the open-plan office space via ducts running along the storage space. All ductwork is to be insulated in a vapour-tight manner with all joints sealed. The insulation is to provide a thermal resistance of 2.5m^{2}K/W or greater. This is in order to prevent heat losses from any extract ducts carrying air to the MHRV unit, as well as preventing heat loss from supply ducts before air is discharged to the occupied space. It is also important to insulate the fresh-air in and stale-air out ducts in order to prevent any condensation on their cold surfaces. Extract air will be drawn from the kitchenette and bathroom using flat boxed ducting running from the suspended floor void up into a newly framed services cavity to terminate close to ceiling level in those rooms. All ducting running in the ventilated floor void will be insulated in the same manner as all ducts running in the services storage area, as previously discussed.	
Heating & DHW	Heating can be provided by a ground source or air-to-water heat pump with COP of 3.0 or greater, supplying heat via low-temperature radiators or via the underfloor heating circuit proposed to be installed over the insulated suspended floor. The heat pump would also provide DHW with storage in a 300-litre cylinder in the plantroom directly adjacent to the building.	
Lighting & Controls	All lighting should be upgraded to LED-only units, with PIR sensors activating lighting in common areas and bathrooms.	
Additional renewables	An analysis of the roof indicates a 6.56kWp peak solar PV system could be installed on the roof providing 5,040 kWh/annum of renewable energy.	

Solar PV installation

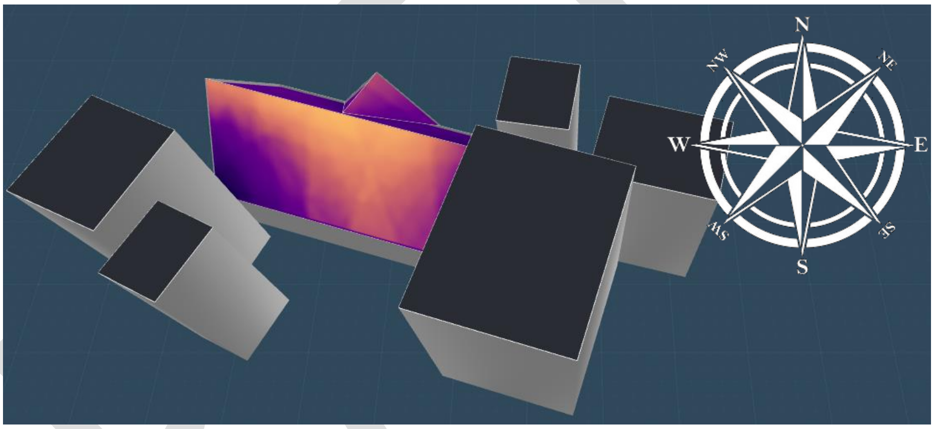
The maximum capacity design of 6.56kWp, recommended for the office building, would yield carbon emission reductions and decrease energy consumption from the grid. The following sub-sections provide a brief overview of the design:

Roof Description

The pitched roof of the building has no major obstacles and is in generally good condition without sign of excessive fouling or lichen growth. There is an asbestos gutter attached to the south-facing roof pitch, which must be considered when installing.

Irradiance Map

The irradiance map depicts the level of solar radiation and shading on the roof. Darker colours indicate more heavy shading, which impacts both the performance and lifetime of PV installations. The building has significant tree overshadowing, and it can be seen that only the upper, central part offers reasonable solar potential.

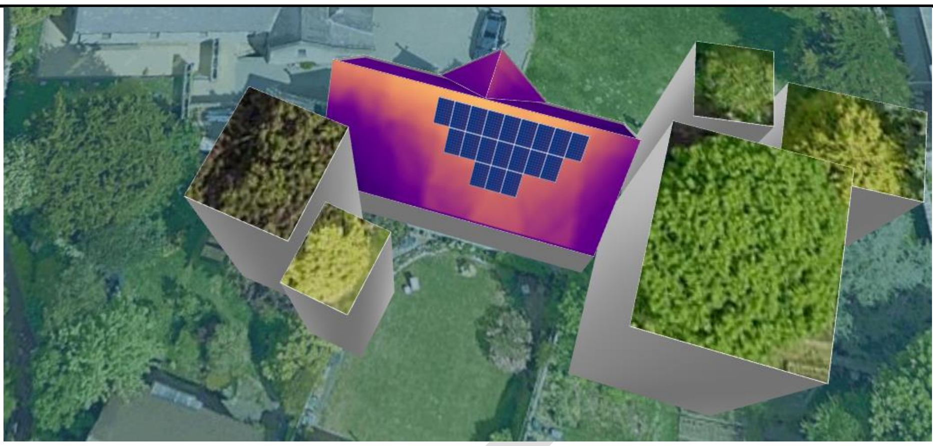


System Design

The below-mentioned system design has the following specifications:

- 6.56kWp system consisting of 19 x 345W PV modules.
- A predicted annual energy production of 5,040kWh/year

From an architectural heritage perspective, effort has been made to mitigate the potential visual effects of the PV panels by partially hiding them from view. While still visible from some viewpoints, consideration should also be given to the energy benefits of solar PV which can outweigh the minimal risk to architectural heritage. PV panels should be installed in such a way that they can be removed with minimal damage to the slates.



Heat Pump System Design

A heat pump system design has been carried out for the office building with the main inputs of the design being the internal floor area of the building, the approximate space heating demand and the approximate hot water demand. From this, an 8kW ground source heat pump (GSHP) can be considered for installation at the office building with the heat pump being served by a horizontal collector area to the North-East of the building. This has benefits from an architectural heritage perspective, as there is no visible outdoor unit. This solution results in higher winter efficiency, however the relative cost is significantly increased due to civil works. A backup electric heating coil is recommended, as discussed further below.

This system design suggests an annual energy delivery of 16,990 kWh/year, with the potential requirement for a small amount of supplementary heating which could be supplied by the existing immersion coil in the hot water storage cylinder.

SUMMARY

Table 19 Energy Improvement of Office Building

Options	Office Building	Energy Rating	Primary Energy $kWh/m^2/yr$	CO_2 Emissions $kgCO_2/m^2$
	Existing Energy Rating	F	740.08	140.96
	Energy Rating Post-Upgrades	B2	188.58	37.08

5.4 NON-RESIDENTIAL - PLACE OF WORSHIP

Note: Data and information on this case study is forthcoming, to be included in the final version of this document.

Figure 74 The main and west elevation of dressed and ashlar cut Kilkenny limestone.

Figure 75 The east elevation in its present condition.

About

This Gothic Revival styled church was constructed between the late 1830s and 1850. The church is orientated southeast-northwest, with the northwest elevation facing the main street. Various extensions were built over the years, including the quadrangle tower (1863) to the northwest, the sacristy (1905), the mortuary chapel (1925) and the baptistery (1950). A number of interventions were also made to the interior of the church in the 1950s and 1960s. The church is an important landmark in the area and it is a Protected Structure.

The roofs are pitched slate roofs, set behind parapets to the side ranges and cast-iron rainwater goods are placed on brackets. The northwest elevation and the tower are of Kilkenny limestone ashlar walls with cut-limestone dressings. The remaining elevations, of which this report is primarily concerned, have unpainted cement-rendered, ruled and lined walls with rendered buttresses and cut-stone quoins. The window openings have limestone surrounds and limestone tracery.

Recent works to the church removed the cement render from the south façade and removed the cement plaster from the inside of the same wall as part of a conservation grant scheme over two years 2016 – 2018. The external façade was re-rendered in a lime render to the original thickness. The interior has not yet been re-plastered due to excessive moisture in the walls.

Pre and Post Retrofit BER
Non-applicable (active place of worship) – As per legislations, no BER was developed for this building.

Status: Protected Structure

Element	Recommendation	U-value (W/m²K)
External walls	After the cement render is removed from all elevations a lime-based render should be applied.	
Internal wall	When the internal walls are to be re-plaster this should be carried out with a lime based insulated plaster	
Roof	The roof is a large cold roof with a dropped ornate plaster ceiling. Externally it has traditional rainwater goods. The external natural slates of the roof are in good condition. Consideration should be given to installing a bio-based insulation at ceiling level and a suitable walkway constructed to protect the insulation and the ceiling. The roof space should be suitably ventilated.	
Floor	The existing terrazzo floor is original and in good condition. This .is an important feature of the building and is likely to be unacceptably damaged by any attempt to lift it.	
Windows	There are stone tracery windows with stained glass. These are historic fabric and cannot be interfered with, there is however, a possibility of installing a suitably designed secondary glazing system and the proposal internal insulated plaster should be returned to all reveals.	
Ventilation	The building is currently not purposefully ventilated, evaluation and consideration should be given to this.	
Heating & DHW	There is an oil-fired boiler wet system. This is large and inefficient and could be improved with the proper assessment. There is also the possibility to introduce radiant panels driven by a more sustainable energy source.	
Additional renewables	Although not a requirement on this project, 4 no. 345W solar PV panels could be installed on the roof for each unit facing east/west either side of the roof ridge. There is also a car park and some grasslands around the church so there is a possibility to consider limited additional PV panels in non-sensitive areas.	

5.5 NON-RESIDENTIAL - SCHOOL

Figure 76 1930s single storey school.

The school is a detached, multiple-bay, single-storey, schoolhouse, built in 1931. The building is roughly U-shaped with projecting wings to the south and has a slight Arts and Crafts appearance. The façade is in semi-coursed rubble stone with roughly dressed granite quoins and brick dressings to the openings. The overhanging pitched roof is mainly gable-ended with a small section between the south projections hipped.

The entire roof is slated and has a rendered chimneystack to west and plain bargeboards. The slates are nailed to battens and on a lime bed which is substantially intact, however with some portions are in need of repair. The main entrance is to the east elevation and consists of a partly glazed replacement timber door with a three-pane rectangular fanlight and stone steps. The windows are of various sizes but with many arranged in groups of three. All have replacement uPVC frames and stone sills. The building retains cast-iron rainwater goods.

The school is occupied from approximately 8am to 5pm each weekday for school purposes. The building is also used on weekends and two evenings per week by various local groups who make use of the music room and drama room. In summer, the building is used for summer camps as well as private hobby classes. Therefore, the building is considered to require continuous heating, hot water and ventilation throughout the year. The ventilation system will be designed to cope with moisture conditions present from both high-density occupancy rates as well as any wet clothes which are brought in on a regular basis in autumn, winter and spring.

Status: Not protected

Element	**Recommendations**	**U-value (W/m^2K)**
External wall	The external wall is solid stone construction and measures c. 510mm in thickness, including an internal lime plaster coat. There are heavy coats of gloss paint on the internal face of the wall. Externally, the pointing and stonework is in excellent condition, with no indications of water ingress or vegetative growth on the façade. The pointing has recently been renewed and is a cementitious mortar. Internally, the paint will be stripped from the walls back to the original lime plaster. A new coat of insulating lime plaster will be applied at a thickness of 40mm to provide a U-value of $0.48W/m^2K$. There are no decorative features internally which need to be maintained or replaced. The modern timber picture rail will be removed, as well as the softwood timber boxing around	0.48

<table>
<tr><td></td><td>the window opes from the installation of the replacement uPVC windows c. 25 years ago. The insulating plaster will return around the window reveals from the wall inner face to the face of the new windows to be installed. The windows will be sealed to the ope using primer and airtightness tape in accordance with manufacturer's recommendations. The internal walls will be painted using a breathable paint.

Figure 77 Brick ope to stone wall with cementitious mortar pointing.</td><td></td></tr>
<tr><td>Roof</td><td>The existing roof consists of a plasterboard finish, with 300mm of glass wool between and over joists. The insulation has been installed well in parts however, areas exist where the insulation has been moved/removed and re-installed with gaps, or not re-installed at all. These areas will be rectified using a similar glass wool product to ensure a consistent insulation thickness and U-value. The U-value of the roof is currently c. 0.133W/m²K. The existing insulation will be retained. Some pipework in the roof is currently uninsulated, which will be rectified with proprietary pipe insulation where these pipes are exposed above the insulation line in accordance with TGD Part J.

Figure 78 Slates on battens and lime bonding.

Figure 79 Uninsulated pipework and gaps in insulation.

An internal masonry spine wall running the length of the central corridor penetrates the insulation line of the ceiling for a distance of c. 750mm above the ceiling line. In order to reduce the thermal bridging effect of this wall penetration, the roof insulation will be carried across the top of the wall. The attic hatch consists of a hinged 18mm OSB board. This will be replaced, including its surrounds, with a proprietary airtight and insulated TGD Part K</td><td>0.133</td></tr>
</table>

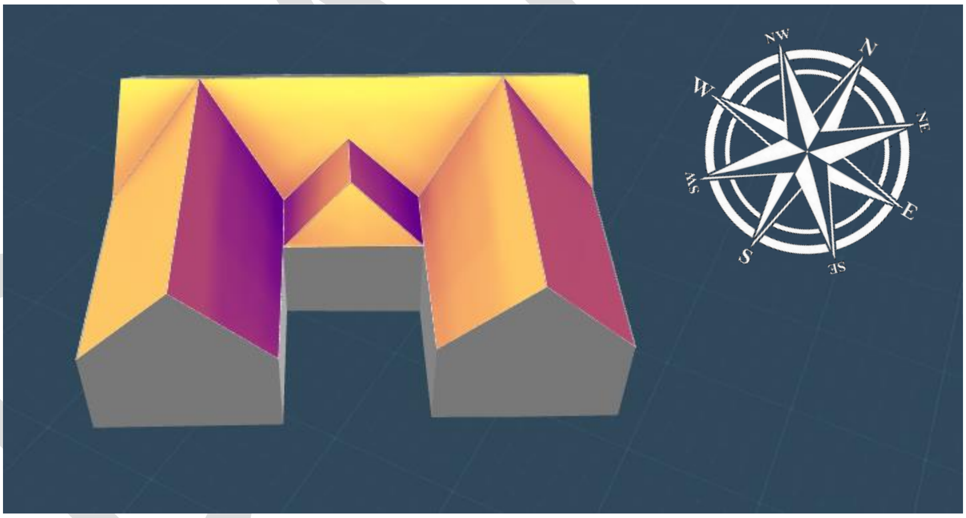
	compliant ladder to provide safe access as well as prevent air exfiltration and heat loss (see section on Ventilation for more information). At present the roof is unventilated. The external stone walling is continuous up to the underside of the slates, with the rafter ends exposed externally. The rafter ends have been found to be in a good state of repair with no evidence of rot or decay. A number of holes will be cored through the stone wall at regular intervals around the perimeter matching the roof angle, in order to allow the installation of sleeved piping to provide ventilation to the roof space. The equivalent clear area of ventilation opening will provide ventilation equivalent to a continuous 25mm vent around the perimeter of the building. The open nature of the attic space will allow cross air flow to occur thus ventilating the attic. The top of the ventilation ducting will be above the top of the attic insulation line.  Figure 80 Exposed rafter ends.	
Windows	The existing windows are 25-year-old white uPVC with double glazing and aluminium spacer bars. The windows are reaching the end of their service life and will be removed as part of the upgrade works. If the windows are not removed at this stage, it is highly likely that they will soon begin to fail, at which point replacement of an entire unit would involve damage to the newly formed insulating opes. The replacement windows will consist of an aluclad timber frame with doubling glazing and warm edge spacer technology, achieving a U-value of 1.4W/m2K. The windows will be airtight sealed to the opes prior to the application of the insulating lime plaster, using proprietary system primer and sealant tape.	1.4

	 Figure 81 Entrance Door.  Figure 82 Internal view of door threshold.  Figure 83 Existing uPVC window. The doors will be replaced with a composite insulated timber door and aluclad timber frame, with a double-glazed upper panel section to maintain the daylight levels currently provided. The doors will achieve an overall U-value of 1.4W/m2K. The door thresholds at either end of the corridor are solid granite and well worn, with extensive ventilation heat losses present. The top step is separate from the lower granite step and will be carefully removed. This will be replaced with a structural insulating threshold detail to provide a warm internal surface at the door threshold and ensure an air-tight seal is maintained.	
Floor	The floor consists of a solid concrete slab on grade. Due to the inefficient horseshoe shape of the building and its relatively small size by school standards, the existing floor U-value is c. 0.7W/m^{2}K. The floor will be removed and replaced with a new floor consisting of a structural slab (thickness in accordance with structural engineer's requirements) on 80mm of rigid insulation on radon membrane on sand blinding on hardcore. The radon barrier will lap up the walls with folded corner joints and be sealed to the external wall inner face using proprietary radon system repair sealant. A 25mm rigid insulation perimeter strip will be installed prior to the insulation of the structural slab in order to provide insulation continuity from the floor slab to the insulating lime plaster. The entrance/exit door thresholds will consist of a structural insulating upstand product which will be continuous with the perimeter insulation.	0.195
Ventilation	At present the school has no purposeful ventilation means with the exception of a single wall vent in one classroom as well as the boiler room (unconditioned space accessed externally), and air infiltration via the door thresholds and other general typical sources of air movement. The school will be fitted with 2 no. mechanical heat recovery ventilation units located in the attic space, each one servicing one half of the school building. The ducting will run along the top of the attic insulation and will be insulated in a vapour-tight manner with thermal resistance of 2.5m^{2}K/W. The fresh-air inlet and stale-air exhaust ducts will penetrate the roof line, with a proprietary slate flashing and grommet solution provided as part of the ducting system. Fresh air will be provided to the classrooms and hobby rooms, with stale air being extracted from toilets/bathrooms as well as over the kitchenette in the staff room. The central spine corridor will act as a circulation space to allow for air movement between supply and extract zones. The system will be sized in order to meet the requirements of the Department of Education as well as TGD Part F.	

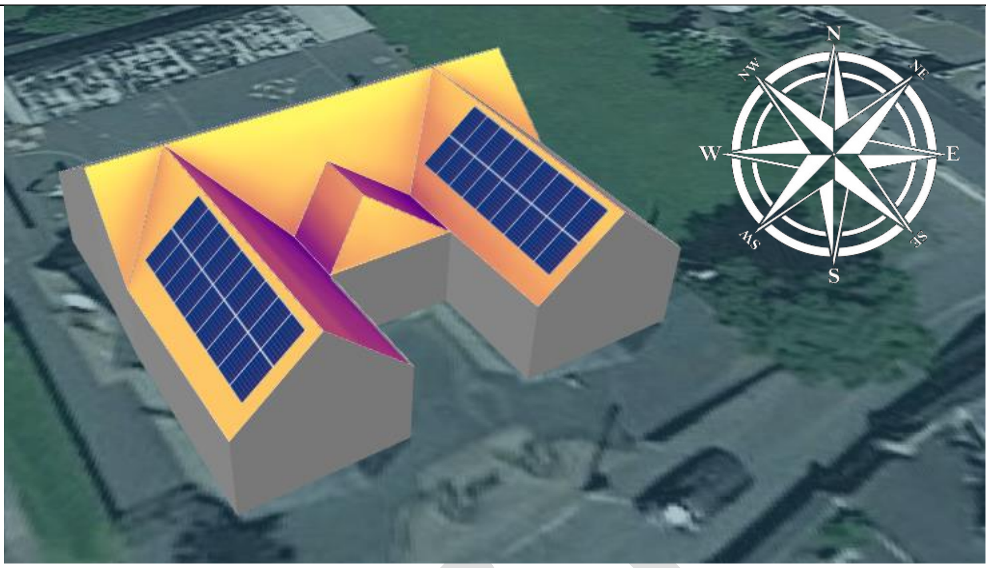
<table>
<tr><td></td><td>The MHRV units will be placed on an 18mm OSB deck, raised above the insulation line by 225mm counter-joists over the existing joists at 300mm centres. A gap of 50mm will be maintained between the top of the insulation and the underside of the OSB decking in order to provide free air flow and prevent mould growth on the underside of the OSB. The new attic hatches (discussed earlier) will be installed adjacent to the MHRV units, to allow safe access for the purpose of filter changes as well as routine maintenance/inspection.</td></tr>
<tr><td>Additional renewables</td><td>Solar PV installation
The maximum capacity design of 12.42kWp, recommended for the office building, would yield carbon emission reductions, and decrease energy consumption from the grid. The following sub-sections provide a brief overview of the design:

Roof Description
The roof is of good quality and shows no evidence of excessive soiling or lichen growth. Structural loading is unlikely to be of concern here.

Irradiance Map
The irradiance map depicts the level of solar radiation and shading on the roof. Darker colours indicate more heavy shading, which impacts both the performance and lifetime of PV installations. Irradiance is highest on the south-east facing pitch, however the geometry of these presents a challenge from an install perspective. The two pitches on the wings which face south-west experience good irradiation and present a lower complexity install. Their production would be focused during the latter part of the day. The north-west face has negligible irradiation, and on the north-east pitches it is also low.



System Design
The below-mentioned system design has the following specifications:
• 12.42kWp System with 36 x 345W solar panels
• 11,160 kWh annual production</td></tr>
</table>



Heat Pump System Design

A heat pump system design has been carried out for the school with the main inputs of the design being the internal floor area of the building, the approximate space heating demand, and the approximate hot water demand. From this, a 12kW air to water heat pump can be considered for installation at the school with the outdoor unit being installed to the rear of the building where drainage and noise present no challenges.

This system design suggests an annual energy delivery of 28,410 kWh/year of heat, requiring 745 kWh/year in supplementary energy which could be provided by an immersion coil in the hot water storage cylinder, or another suitable supplementary heating source. Overall, this system design would provide approximately 21,209 kWh/year in energy savings and 1,927 $kgCO_2$/year in CO_2 savings. Under these assumptions, the use of back-up heating is recommended due to the very low volume of utilisation, in exchange for significant savings in heat pump capacity.

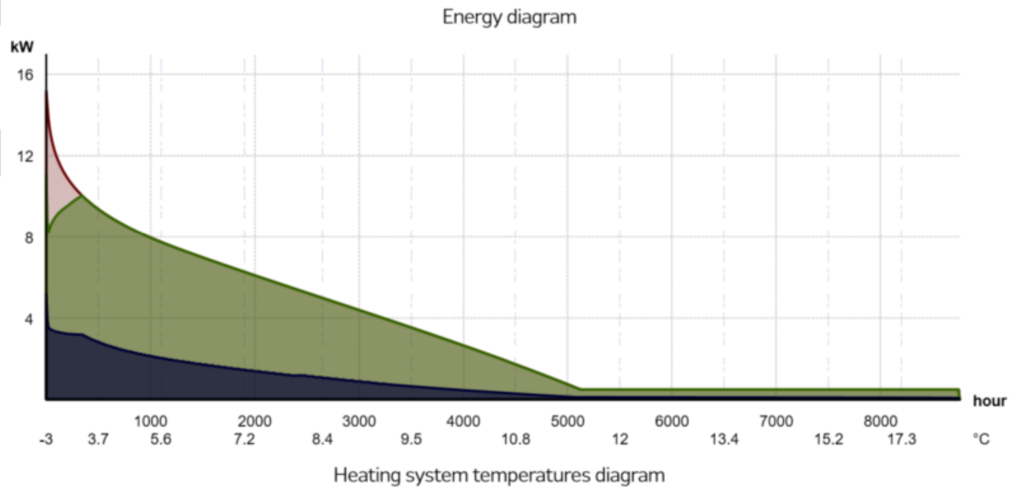


Figure 84 Energy Diagram for the Air to Water Heat pump.

5.6 RESIDENTIAL – DETACHED URBAN/RURAL (BER UPGRADE FROM G TO A1)

Figure 85 Detached urban dwelling front façade.

This building was constructed in c. 1800 and is a former tannery master's dwelling house. The building is currently derelict and vacant so the BER was calculated based on an occupied condition state and default values for the period of the building. The building is a Protected Structure. The building consists of a five-bay two-storey range with dormer attic. The building is constructed with random rubble limestone walls (approx. 600mm thick) with painted roughcast to the road fronting (south) elevation. The windows have square-headed openings with cut-stone sills and timber sash window frames. Doors have square-headed openings (including one to first floor) with timber lintels, and glazed tongue-and-groove timber panelled doors. Carriageway is square-headed with a lintel and a glazed tongue-and-groove timber panelled (accordion) door. Square-headed slit-style apertures to road fronting (south) elevation with fittings not discerned.

The building is currently in a poor state of repair, requiring significant repair to the stonework, which is exposed to the sides and rear. The roof is in poor condition with the majority of rafters to be repaired/replaced. The majority of the slate is however still in place. The rainwater goods have failed in places and a significant amount of vegetative growth is present along the eaves to the rear.

Pre and Post Retrofit BER
Pre-retrofit: G*
Post-retrofit: A1 (A3 without PV panels)

* The existing building BER is calculated as G, assuming an occupied condition and default values for all parameters in accordance with the period of the building.

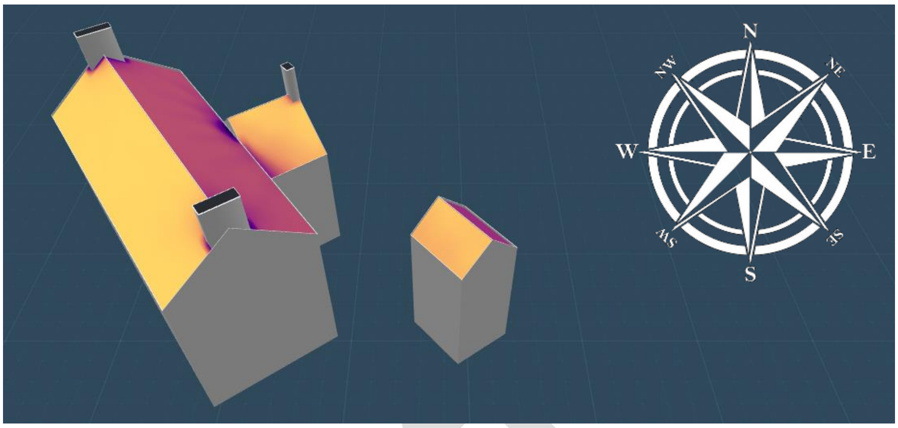
Energy Assessment	The existing floor is a concrete slab in poor condition and uneven, with no vapour control or radon membrane, which will be removed down to grade to allow for a new insulated slab on grade. The external walls are stone rubble construction. There is a large amount of vegetative growth on the facade which will be removed prior to any works. Where mortar joints have been damaged by growth, the mortar will be repaired

	once a suitable herbicide has been applied to prevent further growth. All lime mortar pointing is to be repaired by a subcontractor. The roof rafters are in reasonable condition throughout. Where some rafters were beyond use at the eaves level due to water/moisture ingress at the fascia, these rafters are to be spliced and repaired. Similarly, where any wall plate areas show signs of decay or softness, these are to be repaired/replaced. The windows are single glazed timber frame sash windows and are in such poor condition that they cannot be repaired and will be removed and replaced.	
Element	**Recommendation**	**U-value (W/m²K)**
External wall	The external walls to the sides and rear will receive a new lime render to prevent direct driving rain penetration of the stone rubble wall at lime mortar joints. Internally, the wall will receive a lime parge coat to provide a flat working surface. Onto this, a calcium silicate board will be bonded using a proprietary system adhesive. The calcium silicate board will be applied in a 60mm thickness to achieve a U-value of 0.45W/m²K. The system will be finished with an internal lime plaster finish and breathable paint. The building consists of some original picture rails and decorative cornicing, which will be retained. The picture rail will be removed carefully and stored for reinstatement, with any damaged, rotting or missing pieces replaced with a copied moulding to match the original. The cornices will be left in place during the works, as will the lath and plaster ceilings throughout. The calcium silicate board will be installed using a tapered board from the picture rail to cornicing, prior to reinstatement of the picture rail. At intermediate floor level, the upper floorboards will be removed, and the joist void filled with calcium silicate board on system adhesive at the outer walls as per the room space walls. The joints to the ceiling below and floor joists will be sealed using flexible air-tight system sealant. The floorboard will be cut as necessary to allow continuity of the insulation from the upper wall into the intermediate floor prior to reinstallation/replacement. Where the insulation meets the floor slab (discussed further below), the insulation will be taped and sealed to the floor slab using proprietary system airtightness tape, with the floor cleaned and primed prior to installation. Where the insulation meets the stone internal wall, the insulation is to abut the wall on either side. The internal stone wall will receive a new lime plaster finish coat and will also be sealed to the ground floor slab in the same manner as the external wall/floor slab junction. Thermal modelling shows that no risk of internal surface condensation exists at the internal/external wall junction, which is due to the thickness of the existing wall and sufficient thermal resistance provided by same. At the first-floor eaves level, the existing lath and plaster ceilings will be retained and repaired locally where some cracking and debonding has occurred. The lime plaster for the calcium silicate boarding will be brought up to meet the existing plaster cornicing, provided an airtight continuous line around the building.	0.45
Roof	The existing slates will be removed and stored for re-instatement. The roof rafters will be removed completely, with the joists	0.12

	remaining in place. The building will be protected from the elements by means of a full weather-tight covering over the scaffold in order to provide a dry working environment as well as preventing any rain from falling on the retained and now exposed lath and plaster ceiling. The wall plate will be inspected at this point and repaired/replaced locally as necessary. A vapour control layer will be draped over the joists to follow the line of the ceiling. At the eaves and gables, the airtightness/VCL will be sealed to the cornicing from above and to the gable wall in accordance with manufacturer's recommendations. Flexible wood fibre insulation will be rolled out between joists (depth 150mm) with a further 200mm of wood fibre insulation rolled out perpendicular to this, achieving a U-value of 0.12W/m^{2}K. A new roof structure will be installed, with proprietary over-fascia ventilators installed. The new rafters will have a breather membrane fixed to the top, with a counter batten and slating batten then installed. New ridge ventilators will be installed in order to provide sufficient ventilation of the roof over the breather membrane and provide compliance with TGD Part F. New fascia and soffit boards will be installed, with new cast iron rainwater goods also installed.	
Floor	The floor is in a poor state of repair, with significant cracking and unevenness to the concrete slab. The floor will be removed and replaced with a new floor consisting of a structural slab (thickness in accordance with structural engineer's requirements) on 80mm of rigid insulation on radon membrane on sand blinding on hardcore. The radon barrier will lap up the walls with folded corner joints and be sealed to the external wall inner face using proprietary radon system repair sealant. A 25mm rigid insulation perimeter strip will be installed prior to the insulation of the structural slab in order to provide insulation continuity from the floor slab to the insulating lime plaster. The entrance/exit door thresholds will consist of a structural insulating upstand product which will be continuous with the perimeter insulation.	0.195
Windows	The windows are in a poor state of repair and are exhibiting areas of significant rot around the frame likely due to consistent condensation due to the high U-value of the single glazing. The windows will be replaced with timber sash windows with a slimline vacuum insulated double glazed units. Internally, the existing panelling and shutters will be removed for restoration and reinstated. The calcium silicate board will return across the window reveal at a thickness of 20mm, for which there is ample room in the existing framing, which will be re-installed. The windows will be taped and sealed to the calcium silicate board using proprietary system airtightness tape prior to the reinstatement of the panelling and shutter boxes.	1.6

	 Figure 86 Existing window and surrounds.
Ventilation	The building will be ventilated by means of a demand-control ventilation system. This will consist of a central extract fan located in the attic and terminating at a roof cowl. This will keep the building under constant negative pressure, drawing fresh air in through trickle vents in the windows which will open and close depending on the moisture levels in the building. The area of openings provided will be in compliance with TGD Part F.
Heating & DHW	Space heating could be provided using an air-to-water heat pump with low temperature radiators sized to provide the calculated heat load at a temperature of 45°C. The heat pump could also cater for all domestic hot water needs. An air-source unit was opted for here as there is insufficient space for a horizontal collection system, and no possible access for a boring machine. There are no nearby water sources for a WSHP, and there is a good location for an outdoor ASHP unit, with appropriate drainage, no acoustic sensitivity and good proximity to the main building.
Lighting & controls	All lighting is to be upgraded to LED or low-energy fitting, with PIR sensor controls in hallways and WCs.
Additional renewables	Solar PV installation The roof can be fitted with 10 no. 345W solar PV panels facing southwest. The recommended maximum capacity design of 3.45kWp would yield carbon emission reductions and decrease energy consumption from the grid. The following sub-sections provide a brief overview of the design: Roof Description The roof design is based on the old building designs. The pitched roof has two elevated chimney stacks, with significant vegetation, which should be removed prior to PV installation. Irradiance Map The irradiance map depicts the level of solar radiation and shading on the roof. Darker colours indicate more heavy shading, which impacts both the performance and

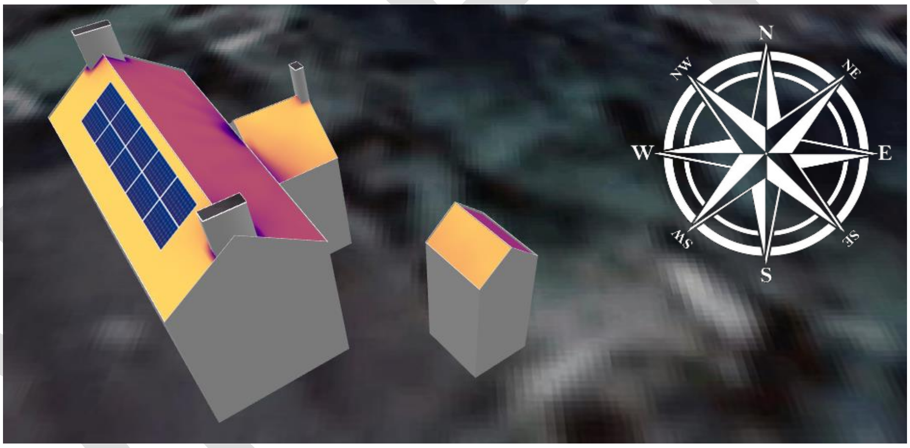
lifetime of PV installations. As per the irradiance map, the south-west facing roof pitch is the only appropriate option for a solar PV install.



System Design

The below-mentioned system design has the following specifications:

- 3.45kWp System with 10 x 345W PV panels
- 3,020 kWh annual energy production



SUMMARY

Table 20 Energy Improvements for Detached Urban/Rural Dwelling.

Options	**Detached Urban/Rural Dwelling**	**Energy Rating**	**Primary Energy $kWh/m^2/yr$**	**CO_2 Emissions $kgCO_2/m^2$**	**HLI**
	Existing Energy Rating	G	575.97	141.31	7.49
1	Fabric Upgrade	D2	267.83	62.12	2.71
2	Ventilation and air tightness	D1	249.68	60.52	2.42
3	Heat Pump Upgrade	A3	70.36	13.84	
4	PV Panels 3.5 kW	A1	23.62	4.64	

5.7 RESIDENTIAL - END OF TERRACE VICTORIAN

Note:

data and information on this case study is forthcoming, to be included in the final version of this document.

5.8 RESIDENTIAL – END OF TERRACE EDWARDIAN

Note: data and information on this case study is forthcoming, to be included in the final version of this document.

5.9 RESIDENTIAL - MID-TERRACE GEORGIAN (BER UPGRADE D2 TO A1)

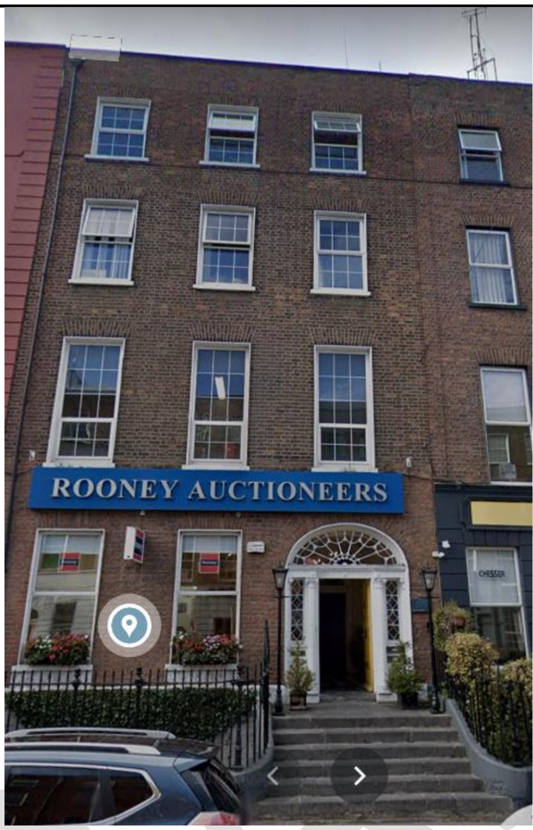


Figure 87 Front elevation of the mid-terrace Georgian building.

The building was likely originally constructed as a single-family dwelling and has been converted to commercial use at some point. As the intention is to restore it to residential use, the retrofit measures and improvements are based on residential use.

The building is a 4-storey-over-basement Georgian mid-terrace with brown solid brick walls (approx. 550mm thick) and been repointed with lime cement mortar. The building is in active use and is maintained as a heated and dry environment in good repair. The building has undergone interior renovation numerous times over the years, and does not have any notable period features such as cornices, ceiling roses, picture rail etc. The windows are a mixture of replacement PVC mock-sash and aluminium framed sash windows. The Georgian door, rose window and sidelights are original and will be retained without interference. The basement is also a heated dry environment without any indications of significant moisture ingress at floor or wall level. The basement walls to the front and rear are exposed to the ambient environment, while the side walls are party walls to neighbouring properties.

Pre and Post Retrofit BER:
Pre retrofit: D2
Post retrofit: A1 (A2 without solar PV, B2 without heat pump upgrade)

Element	Recommendation	U-value (W/m^2K)
External wall	The external wall will have an internal lining of 60mm calcium silicate board applied on a layer of levelling lime adhesive, and internal system lime plaster applied to achieve a wall U-value of	0.45

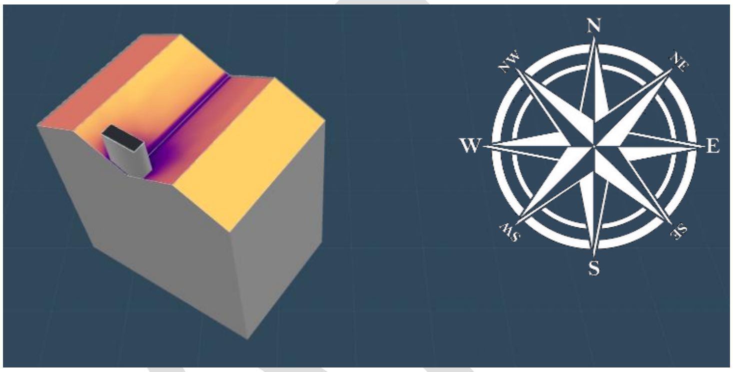
	$0.45W/m^2K$. Any existing internal cementitious or gypsum-based plaster will be removed back to the brick face, which will be thoroughly cleaned prior to application of the levelling lime adhesive layer. At intermediate floors, the ceiling and floorboards will be removed around the perimeter, the floor joists and walls cleaned thoroughly, and the calcium silicate board continued between floors joists to provide continuity with the insulation above and below. The calcium silicate boards will be sealed to the joists on either side, ceiling below, and joist upper faces, using proprietary airtightness sealant and tapes. Externally the lime mortar pointing was inspected and found to be in good condition without any current need for repair. As the building and rainwater goods have been well maintained, there are no current water ingress issues or fabric issues which require remediation.	
Roof	The roof consists of a double pitched roof with central valley and parapets on both elevations. The slates and roof structure were visually inspected and found to be in good condition. There are no missing slates, valleys and parapet gutters are clear of debris, and have been well maintained. Insulation will be rolled out between and over joists from within the attic space. Rolls over joists will be placed perpendicular to those between joists and installed in a manner that does not result in any gaps between insulation layers. The insulation will consist of 100mm wood fibre roll between rafters and 250mm above and perpendicular to the joists, with thermal conductivity of 0.044W/mK. In the room spaces below, a vapour control layer will be applied to the underside of the existing ceiling. This membrane will be taped and sealed to the surrounding walls prior to plastering. The tape will have a key for adhesion of plaster. Following this, a 50mm services zone will be installed perpendicular to the ceiling joists. All cabling or services will be in this zone only, with all penetrations of the existing ceiling sealed. Where any holes exist at partition heads, these should be sealed from above prior to any installation of insulation, and new services installed in the new services zone only. Onto the service cavity batten will be affixed a 12.5mm gypsum plasterboard with 3mm skimcoat plaster. At eaves level, a low-vapour-resistance card is to be fitted between rafters to maintain a gap between the insulation at eaves level and the roof felt. The insulation in the service cavity will provide insulation continuity at the external wall/ceiling junction. The roof will have slate vents installed on all pitches due to the lack of airflow across the valley in the centre. The extent of ventilation openings will comply with Technical Guidance Document Part F. A vent will also be installed in the two gables either side of the valley in order to encourage convection within the roof space.	0.12
Floor	The basement floor forms the thermal envelope of the building. Its current U-value is $0.43W/m^2K$. The existing floor slab will be removed and replaced with an insulated structural slab on grade.	0.2

	The floor will consist of a structural slab (specification as per structural engineer's recommendation) on a separating vapour control layer on 140mm XPS insulation on radon barrier on sand blinding on compacted hardcore. The radon barrier is returned up to 150mm above finished floor level and sealed to the lime parge coat. The floor slab will also have a 30mm XPS perimeter strip installed. The separating VCL layer will be lapped up the wall above finished floor level to allow lapping and sealing onto the vapour control layer of the dry-lining system. At the gable wall the vapour control layer of the floor slab will lap 100mm up the wall and be sealed to the lime parge coat. The joint will be concealed behind a new skirting board.	
Basement walls	The front and rear walls of the basement are of the same type, albeit with the brick exposed internally. These walls will first have a lime plaster coat applied, prior to installation of the same insulating finish system as the above ground areas.	0.45
Windows	The windows in the building are currently a mix of PVC (c. 20 years old) and non-thermally-broken aluminium. Both windows suffer from condensation on the glazing and/or frame units in winter and will therefore be replaced. Therefore, the windows will be removed and replaced with new aluclad timber casement windows with triple glazing units and warm edge spacers, to achieve an overall U-value of 1.1W/m2K. The windows will be taped and sealed to the opes on all sides using a proprietary air-tight sealing system. The window design will match the existing windows.	1.1
Ventilation	The building will be fitted with a demand control ventilation system consisting of two fans. The extract fan units will be installed in the attic. The existing flue system, which is no longer in use, will be used to duct the extract fans to the room spaces below. Architecturally-suitable grille vents will be installed on the chimney breast in each room space to allow air flow from the room. Locations will be chosen on each room chimney breast to break into the relevant flue being used for the extract. Any flues not being used will be capped at the pot as well as having a chimney balloon installed at the fireplace. In living rooms and bedrooms, new cores will be introduced through the external walls, located on the gable into the adjacent laneway for any rooms on the gable wall, or to the front and rear walls for rooms which face only those walls. An architecturally-suitable wall grille or vent brick will be installed at these locations externally. The kitchen and bathrooms, which do not have a fireplace present, will have extract fans ducted directly to the external walls, with extract units and flow rates installed in compliance with Technical Guidance Document Part F.	
Heating & DHW	Heating & domestic hot water could be provided via an air-to-water heat pump located to the rear of the building.	
Additional renewables	The roof has been assessed and could be fitted with 18 no. 345W solar PV panels generating 5,320 kWh/year of electricity. Solar PV installation	

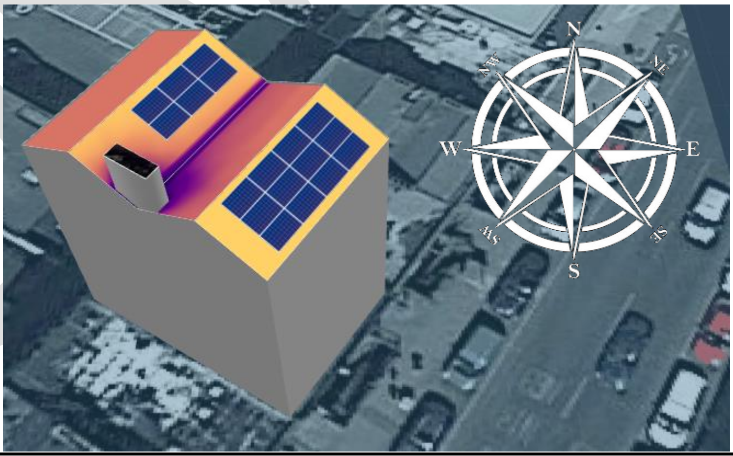
The recommended maximum capacity design of 6.21kWp, would yield carbon emission reductions and decrease energy consumption from the grid. The following sub-sections provide a brief overview of the design:

Roof Description
The roof Appears to be of good quality, with no evidence of excessive soiling or lichen growth. Structural loading is unlikely to present a concern.

Irradiance Map
The irradiance map depicts the level of solar radiation and shading on the roof. Darker colours indicate more heavy shading, which impacts both the performance and lifetime of PV installations. The dual pitched roof has no significant obstacles and good solar potential; however, the chimney stack offers significant local shading and proximity to this stack should be avoided during an install.



System Design
The below-mentioned system design has the following specifications: 6.21kWp system with 18 x 345W PV panels.
Annual Energy production of 5,320kWh/year



SUMMARY

Table 131 Energy Improvements for Mid-Terrace Georgian

Options	Mid-Terrace Georgian	Energy Rating	Primary Energy kWh/m²/yr	CO_2 Emissions $kgCO_2/m^2$	HLI
	Existing Energy Rating	D2	270.28	50.12	2.76
1	Fabric Upgrade	B3	129.21	24.09	1.3
2	Ventilation and air tightness	B2	100.63	18.85	0.96
3	Heat Pump Upgrade	A2	30.25	5.95	0.96
4	PV Panels 6.21 kWp	A1	10.86	2.14	

6 APPENDIX

6.1 ADDITIONAL ESSENTIAL GUIDANCE ON THE ENERGY RETROFIT OF TRADITIONAL BUILDINGS

6.1.1 *STANDARDS AND BUILDING REGULATIONS*

- BRE Information Paper 1/06 Assessing the effects of thermal bridging at junctions and around openings (BRE Group, 2006a)
- BRE Report BR 262, Thermal Insulation: avoiding risks (BRE Group, 2002)
- BRE Report BR 443, Conventions for U-value calculations (BRE Group, 2006b)
- BRE Report BR 497, Conventions for calculating linear thermal transmittance and temperature factors (BRE Group, 2016)
- British Standard BS 7913: 2013 Conservation of Heritage Buildings (European Committee for Standardisation, 2013)
- European Standard I.S. EN 15026:2007 Hygrothermal Performance of Building Components and Building Elements - Assessment of Moisture Transfer by Numerical Simulation (European Committee for Standardisation, 2007)
- European Standard I.S. EN 16883:2017 Conservation of Cultural Heritage - Guidelines for Improving the Energy Performance of Historic Buildings (European Committee for Standardisation, 2017)
- European Standard I.S. EN ISO 6946:2017 Building components and building elements – Thermal resistance and thermal transmittance – Calculation methods (European Committee for Standardisation, 2017)
- I.S. EN 12667: 2001 Thermal performance of building materials and products – Determination of thermal resistance by means of guarded hot plate and heat flow meters method – Products of high and medium thermal resistance (International Organisation for Standardisation, 2001)
- I.S. EN ISO 10211:2007 Thermal bridges in building construction – Heat flows and surface temperatures – Detailed calculations (International Organisation for Standardisation, 2007)
- I.S. EN ISO 13788:2012 Hygrothermal performance of building components and building elements - Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation Methods (International Organization for Standardisation, 2012)
- PAS 2035:2019 Retrofitting Dwellings for Improved Energy Efficiency (British Standards Institution, 2019)
- Technical Guidance Document – Part F: Ventilation (DHPLG, 2019a) and all I.S., EN, ISO, BS and other guidance documents referred to therein

- Technical Guidance Document - Part L: Conservation of Fuel and Energy - Dwellings (DHPLG, 2019b) and all I.S., EN, ISO, BS and other guidance documents referred to therein
- Technical Guidance Document – Part L: Conservation of Fuel and Energy – Buildings other than Dwellings (DHPLG, 2017) and all I.S., EN, ISO, BS and other guidance documents referred to therein

6.1.2 *TECHNICAL GUIDANCE & RESEARCH REPORTS*

- Advice Series: Energy Efficiency in Traditional Buildings (Donnelly, 2007)
- Architectural Heritage Protection: Guidelines for Planning Authorities (*Architectural Heritage Protection: Guidelines for Planning Authorities*, 2011)
- Bringing Back Homes - Manual for the Reuse of Existing Buildings (Department of Housing Local Government and Heritage, 2018)
- CIBSE Guide A: Environmental design - Section 3: Thermal properties of buildings and components (CIBSE, 2015)
- Deep Energy Renovation of Traditional Buildings: Addressing Knowledge Gaps and Skills Training in Ireland (Engel Purcell, 2018)
- Energy Efficiency and Historic Buildings: How to Improve Energy Efficiency (McCaig et al., 2018)
- Energy Efficiency and Traditional Homes (McCaig, 2020)
- Guidance from the Society for the Protection of Ancient Buildings (SPAB), including The SPAB Research Reports (SPAB, 2020)
- Historic Environment Scotland (HES) Refurbishment Case Studies (Historic Environment Scotland, 2020b) Technical Papers (Historic Environment Scotland, 2020d), Inform Guides (Historic Environment Scotland, 2020a) and Short Guides (Historic Environment Scotland, 2020c).
- Historic Environment Scotland (HES) Technical Paper 1: Thermal Performance of Traditional Windows (Baker, 2010)
- Historic Environment Scotland (HES) Technical Paper 10: U - values and Traditional Buildings - In Situ Measurements and their Comparisons to Calculated Values (Baker, 2011)
- Historic Environment Scotland (HES) Technical Paper 15: Assessing Risks in Insulation Retrofits using Hygrothermal Software Tools - Heat and Moisture Transport in Internally Insulated Stone Walls(Little et al., 2015)
- Historic England, Traditional Windows: Their Care, Repair and Upgrading (Pickles, McCaig and Wood, 2017)
- Hygrothermal Risk Evaluation for the Retrofit of a Typical Solid-Walled Dwelling (Arregi and Little, 2016)
- In-Situ Measurements of Wall U-values in English Housing (Hulme and Doran, 2014)

- Moisture in Buildings: An Integrated Approach to Risk Assessment and Guidance (May and Sanders, 2017)
- Old House Eco Handbook : A Practical Guide to Retrofitting for Energy Efficiency and Sustainability (Hunt and Suhr, 2019)
- Proceedings from the international technical conference on Energy Efficiency and Comfort of Historic Buildings (EEHB, 2018, EEHB, 2016)
- Responsible Retrofit Series: Planning responsible retrofit of traditional buildings, STBA (May and Griffiths, 2015)
- Responsible Retrofit Series: What is Whole House Retrofit (STBA, 2016)
- Solid Wall Heat Losses and the Potential for Energy Saving: The Nature of Solid Walls In-Situ (Hulme, 2016)
- Sustainable Renovation: Improving Homes for Energy, Health and Environment (Morgan, 2018)
- Technical and best practice guidance from Historic England , including their Energy Efficiency and Historic Buildings guidance series (Historic England, 2020) *Note: Excluding Energy Efficiency and Historic Buildings: Insulating solid walls.*
- The Responsible Retrofit Knowledge Centre (STBA, 2020)
- The SPAB Building Performance Survey: Final Report (ArchiMetrics Ltd., 2019)
- The Sustainable Traditional Building Alliance Responsible Retrofit Wheel (STBA, 2017)
- There's no place like old homes: Re-use and recycle to reduce carbon (Leeson, 2019)
- Thermal Insulation Materials for Building Applications: The Complete Guide (Latif et al., 2019)
- Understanding Carbon in the Historic Environment Scoping Report and Case Study Extension (Duffy et al., 2020a, Duffy et al., 2020b)
- S.R. 54:2014 Code of practice for the energy efficient retrofit of dwellings (National Standards Authority of Ireland, 2019)

Note: According to S.R 54, this document 'may not be appropriate for dwellings which, although not protected structures or proposed protected structures, may be of architectural or historical interest' and 'some traditional buildings perform and respond to the outside/inside environment differently from more modern/mid-to-late 20th Century buildings'.

6.1.3 *TGD PART L – COST OPTIMAL WORKS ACTIVATED BY RENOVATION WORKS*

Table 7 - Cost Optimal Works activated by Major Renovation

Major Renovation > 25 % surface area[1,2,3,5]	**Cost Optimal level as calculated in DEAP (Paragraph 2.3.3 a.)**	**Works to bring dwelling to cost optimal level in so far as they are technically, economically and functionally feasible (Paragraph 2.3.3 b.)**
External walls renovation	The cost optimal performance level to be achieved is 125 $kWh/m^2/yr$.	Upgrade insulation at ceiling level (roof) where U-values are greater than in Table 5 and Oil or gas boiler replacement[6] and controls upgrade where the oil or gas boiler is more than 15 years old and efficiency less than 86 % and/or Replacement of electric storage heating[7] systems where more than 15 years old and with heat retention not less than 45 % measured according to IS EN 60531.
External walls and windows renovation		
External walls and roof renovation		
External walls and floor renovation		
New Extension affecting more than 25 % of the surface area of the existing dwelling's envelope (see 2.3.6)	The cost optimal performance level to be achieved is 125 $kWh/m^2/yr$	Upgrade insulation at ceiling level (roof) where U-values are greater than in Table 5 and Oil or gas boiler replacement[6] and controls upgrade where the oil or gas boiler is more than 15 years old and efficiency less than 86 % and/or Replacement of electric storage heating[7] systems where more than 15 years old and with heat retention not less than 45 % measured according to IS EN 60531 and Upgrade insulation at wall level where U-values are greater than in table 5.
Windows Renovation	Not applicable[4]	Not applicable[4]
Roof Renovation		
Floor Renovation		
Roof and windows renovation		
Windows and floor renovation		
Roof and floor renovation		

[1] Where works are planned as a single project.
[2] Where major renovations to walls, roofs and ground floors constitute essential repairs e.g. repair or renewal of works due to fire, storm or flood damage or as a result of a material defect e.g. reactive pyrite in sub-floor hardcore, it is not considered economically feasible to bring these renovations to a cost optimal level.
[3] Major Renovation of external wall elements should also meet the requirements of Table 5
[4] It is not considered technically, functionally or economically feasible to bring the whole building to cost optimal level when replacing the surface area of these elements.
[5] Subject to the requirements of Table 5 for Material Alterations and window and door replacement.
[6] Oil or gas boiler replacement should be with a boiler or a renewable energy source with an efficiency as given in section 2.2.2.
[7] Replacement of electric storage heating should be with a heat generator with an efficiency as given in section 2.2.2.

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